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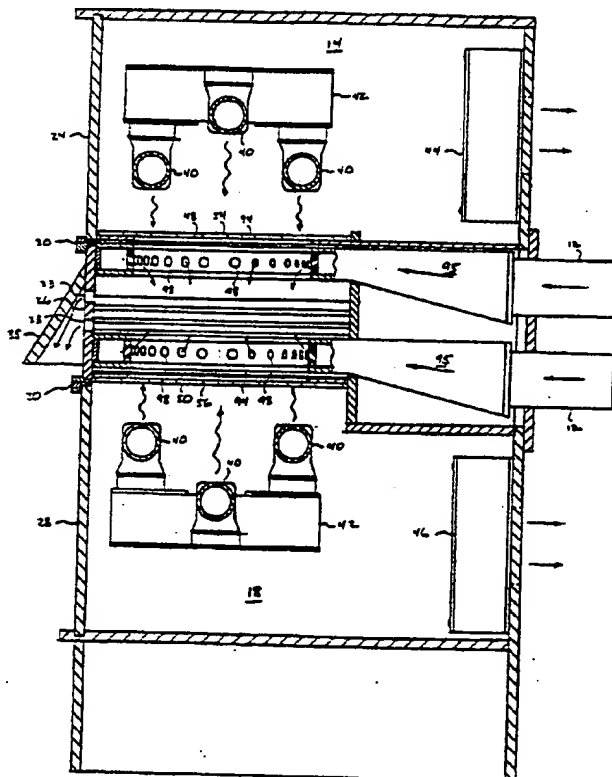
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## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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**(54) Title:** APPARATUS AND PROCESS FOR LENS CURING AND COATING**(57) Abstract**

Method, apparatus and composition for making and coating a plastic lens. The method comprises disposing a liquid composition and a photosensitive initiator into a mold cavity and directing ultraviolet light to act on the lens forming material in the cavity to produce a lens therefrom. An improved postcure process and scratch resistant coating process is disclosed.



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DESCRIPTION  
APPARATUS AND PROCESS FOR  
LENS CURING AND COATING

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BACKGROUND OF THE INVENTION

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The present invention relates generally to methods, apparatus and compositions for making plastic lenses.

15 It is conventional in the art to produce optical lenses by thermal curing techniques from the polymer of diethylene glycol bis(allyl)-carbonate (DEG-BAC).

The polymer of DEG-BAC exhibits desirable optical and mechanical properties. These properties include high  
20 light transmission, high clarity, and high index of refraction together with high abrasion and impact resistance. These properties in the past made DEG-BAC one of the leading monomers in the manufacture of high quality lenses, face shields, sun and safety glasses.  
25 Other properties of DEG-BAC, however, such as its slow

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rate of polymerization, make it an undesirable monomer in the manufacture of these items. Moreover, DEG-BAC, without any additives or co-monomers, produces a hard but somewhat brittle polymer that is very prone to cracking.

- 5 In addition, DEG-BAC, without additives, tends to adhere tightly to the lens forming molds, often leading to cracking of the molds.

- 10 In addition, the thermal curing techniques for polymerizing DEG-BAC to produce optical lenses have several disadvantages and drawbacks. One of the most significant drawbacks is that it may take approximately 12 hours to produce a lens according to thermal curing techniques. A lens forming mold, therefore, can produce  
15 at most two lenses per day.

- Moreover, thermal curing techniques employ a thermal catalyst so that a polymerizable mixture of DEG-BAC and catalyst will slowly polymerize even while refrigerated.  
20 The polymerizable mixture therefore has a very short shelf life and must be used within a short time or it will harden in its container.

- Furthermore, the thermal catalysts utilized  
25 according to the thermal curing techniques are quite volatile and dangerous to work with, thus requiring extreme care in handling.

- Curing of a lens by ultraviolet light presents  
30 certain problems that must be overcome to produce a viable lens. Such problems include yellowing of the lens, cracking of the lens or mold, optical distortions in the lens, and premature release of the lens from the mold.

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The present invention is directed to methods, apparatus and compositions for making plastic lenses that



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overcome the disadvantages and drawbacks of the prior art.

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# SUMMARY OF THE INVENTION

The present invention provides methods, apparatus and compositions for making plastic lenses, such as optical lenses for use in eyeglasses and the like.

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In one embodiment of the present invention, a method for making plastic lenses is provided in which a polymerizable lens forming material is disposed in a mold cavity defined in part between a first mold member and a second mold member spaced apart from each other by a gasket. Rays of ultraviolet light are directed against either or both of the first and second mold members or the gasket. In a preferred embodiment, the first and second mold members are cooled. In another preferred embodiment, the ultraviolet light is filtered before it impinges on either or both of the first and second mold members.

In another embodiment of the present invention, an apparatus is provided for making plastic lenses which includes a first mold member and a second mold member spaced apart by a gasket, wherein the first and second mold members define a mold cavity. The apparatus includes a generator for generating and directing ultraviolet light against at least one of the first and second mold members. Alternatively, the apparatus includes a generator for generating and directing ultraviolet light against the gasket. The apparatus may also include a means for preventing the transmission of ultraviolet light through the first and second mold members. In addition, the apparatus may include a filter for filtering the ultraviolet light. The filter may be

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disposed between the generator for generating and directing ultraviolet light and the first mold member, and between the generator for generating and directing ultraviolet light and the second mold member. The apparatus may include a fluid (e.g. air) distributor or a liquid bath for cooling the first and second mold members.

In another embodiment of the invention, the lens forming material may be cooled at relatively low temperatures while being exposed to ultraviolet ("UV") light. The lens forming material may be cooled by directing various flowrates of cooling air towards the mold members. The mold members themselves may be made thinner or thicker to achieve optimum lens curing results. Different lens curvatures may be made from the same mold members by varying the UV intensity patterns on the mold members during cure of the lens forming material. Hardness, cure and rigidity of the lenses made as described above may be improved by demolding the lenses and then subjecting the lenses to high intensity UV light and/or heating.

In still another embodiment of the present invention, a photoinitiator is provided which includes methyl benzoylformate. The photoinitiator may be used with a composition that includes at least one polyethylenic-functional monomer containing two ethylenically unsaturated groups selected from acrylyl and methacrylyl. The photoinitiator may be used with a composition that includes at least one polyethylenic-functional monomer containing three ethylenically unsaturated groups selected from acrylyl and methacrylyl.

The compositions may include an aromatic containing bis(allyl carbonate)-functional monomer such as bisphenol A bis (allyl carbonate). The compositions may include 1,6 hexanediol dimethacrylate, trimethylolpropane

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triacrylate, tetraethylene glycol diacrylate and/or tripropylene glycol diacrylate. In a preferred embodiment, the composition photoinitiator also includes 1-hydroxycyclohexyl phenyl ketone.

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#### BRIEF DESCRIPTION OF THE DRAWINGS

The above brief description as well as further  
10 objects, features and advantages of the methods, apparatus and compositions of the present invention will be more fully appreciated by reference to the following detailed description of presently preferred but  
nonetheless illustrative embodiments in accordance with  
15 the present invention when taken in conjunction with the accompanying drawings in which:

Fig. 1 is a perspective view of an apparatus for  
producing a plastic lens according to the present  
20 invention;

Fig. 2 is a cross-sectional view of the apparatus of  
the present invention taken along line 2-2 of Fig. 1;

25 Fig. 3 is a cross-sectional view of the apparatus of  
the present invention taken along line 3-3 of Fig. 2;

Fig. 4 is a detail view of a component of the  
apparatus of the present invention;

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Fig. 5 is a detail view of a component of the  
apparatus of the present invention;

Fig. 6 is a cross-sectional view of a lens cell for  
35 use in the apparatus of the present invention;

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Fig. 7 is a perspective view of an apparatus for producing a plastic lens according to the present invention; and

5        Fig. 8 is a perspective view of an apparatus for producing a plastic lens according to the present invention.

10       Fig. 9 is a schematic block diagram of an alternate process and system for making and postcuring a plastic lens.

15       Fig. 10 is a schematic diagram of an apparatus to apply relatively high intensity light to a lens or mold assembly.

Fig. 11 is a top view of a lens holder.

20       Fig. 12 is a side view of the lens holder shown in Fig. 11.

Fig. 13 is a schematic diagram of a lens curing apparatus with a light sensor and controller.

25       Fig. 14 is a schematic view of the front of a lens curing apparatus.

30       Fig. 15 is a schematic view of the side of a lens curing apparatus.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

35       While various aspects of the present invention are hereinafter illustrated and described as being particularly adapted for the production of a plastic lens for use in eyeglasses, it is to be understood that lenses

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for other uses can also be produced, such as safety glasses as well as lenses having high quality optical use for instrument sightings, photography and light filtration.

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Therefore, the present invention is not to be limited only to the embodiments illustrated in the drawings, because the drawings are merely illustrative of the wide variety of specific embodiments of the present invention.

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Referring now to Fig. 1, a plastic lens curing chamber of the present invention is generally indicated by the reference numeral 10. The lens curing chamber 10 communicates through a plurality of pipes 12 with an air source (not shown), the purpose of which will be discussed below.

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As shown in Fig. 2, the plastic lens curing chamber 10 may include an upper lamp chamber 14, an irradiation chamber 16, and a lower lamp chamber 18. The upper lamp chamber 14 may be separated from the irradiation chamber 16 by a plate 20. The lower lamp chamber may be separated from the irradiation chamber 16 by a plate 22. The upper lamp chamber 14, the irradiation chamber 16, and the lower lamp chamber 18 may be isolated from ambient air by means of upper lamp chamber doors 24, irradiation chamber doors 26, and lower lamp chamber doors 28, respectively. While the upper lamp chamber doors 24, the irradiation chamber doors 26 and the lower lamp chamber doors 28 are shown in Fig. 1 as including two corresponding door members, those of ordinary skill in the art will recognize that the doors 24, 26 and 28 may comprise a single door member. The upper lamp chamber doors 24, the irradiation chamber doors 26 and the lower lamp chamber doors 28 may be slidably mounted in guides 30. As shown in Fig. 2,

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vents 32 may communicate with upper lamp chamber 14 and lower lamp chamber 18 by way of corresponding vent chambers 34 and openings 36 disposed in plate 20 and plate 22. Each vent 32 may be shielded by a vent cover 38.

As shown in Fig. 3, vents 33 may be disposed in the irradiation chamber doors 26 and communicate with irradiation chamber 16. Each vent 33 may be shielded by a vent cover 35.

As shown in Figs. 2 and 3, a plurality of light generating devices or lamps 40 may be disposed within each of upper lamp chamber 14 and lower lamp chamber 18. Preferably, upper lamp chamber 14 and lower lamp chamber 18 each include three lamps 40 that are arranged in a triangular fashion in which the lamps 40 in the upper lamp chamber 14 are disposed with the point of the triangle pointing upwards whereas the lamps 40 in the lower lamp chamber 18 are disposed with the point of the triangle pointing downward. The lamps 40, preferably, generate ultraviolet light having a wavelength in the range of approximately 300 nm to 400 nm since the effective wavelength spectrum for curing the lens forming material lies in the 300 nm to 400 nm region. The lamps 40 may be supported by and electrically connected to suitable fixtures 42.

An exhaust fan 44 may communicate with upper lamp chamber 14 while an exhaust fan 46 may communicate with lower lamp chamber 18.

As noted above, the upper lamp chamber 14 may be separated from the irradiation chamber 16 by plate 20. Similarly, lower lamp chamber 18 may be separated from the irradiation chamber 16 by plate 22. The plates 20 and 22 may include apertures 48 and 50, respectively

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through which the light generated by lamps 40 may be directed so as to impinge upon a lens cell 52 (shown in phantom in Fig. 2). The diameter of the lens cell 52 according to the present invention, preferably, is approximately 74 mm. The apertures 48 and 50 preferably range from about 70 mm to about 140 mm. An upper light filter 54 rests upon plate 20 while a lower light filter 56 rests upon plate 22 or is supported by brackets 57. The upper light filter 54 and lower light filter 56 are shown in Fig. 2 as being comprised of a single filter member, however, those of ordinary skill in the art will recognize that each of the upper light filter 54 and lower light filter 56 may be comprised of two filter members. The components of upper light filter 54 and lower light filter 56 preferably are modified depending upon the characteristics of the lens to be molded. For instance, in a preferred embodiment for making negative lenses, the upper light filter 54 includes a plate of Pyrex glass that is frosted on both sides resting upon a plate of clear Pyrex glass. The lower light filter 56 includes a plate of Pyrex glass frosted on one side resting upon a plate of clear Pyrex glass with a device for reducing the intensity of ultraviolet light incident upon the center portion in relation to the edge portion of the lens being disposed between the plate of frosted Pyrex and the plate of clear Pyrex glass.

Conversely, in a preferred arrangement for producing positive lenses, the upper light filter 54 includes a plate of Pyrex glass frosted on one or both sides and a plate of clear Pyrex glass resting upon the plate of frosted Pyrex glass with a device for reducing the intensity of ultraviolet light incident upon the edge portion in relation to the center portion of the lens being disposed between the plate of clear Pyrex glass and the plate of frosted Pyrex glass. The lower light filter 56 includes a plate of clear Pyrex glass frosted

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on one side resting upon a plate of clear Pyrex glass with a device for reducing the intensity of ultraviolet light incident upon the edge portion in relation to the center portion of the lens being disposed between the plates of clear Pyrex glass. In this arrangement, in place of a device for reducing the relative intensity of ultraviolet light incident upon the edge portion of the lens, the diameter of the aperture 50 can be reduced to achieve the same result, i.e. to reduce the relative intensity of ultraviolet light incident upon the edge portion of the lens.

It will be apparent to those skilled in the art that each filter 54 or 56 could comprise a plurality of filter members or comprise any other means or device effective to reduce the light to its desired intensity, to diffuse the light and/or to create a light intensity gradient across the lens cell 52.

Preferably, the upper light filter 54 or the lower light filter 56 each comprise at least one plate of Pyrex glass having at least one frosted surface. Also, either or both of the upper light filter 54 and the lower light filter 56 may include more than one plate of Pyrex glass each frosted on one or both surfaces, and/or one or more sheets of tracing paper. After passing through frosted Pyrex glass, the ultraviolet light is believed to have no sharp intensity discontinuities which is believed to lead to a reduction in optical distortions in the finished lens. Those of ordinary skill in the art will recognize that other means may be used to diffuse the ultraviolet light so that it has no sharp intensity discontinuities.

Disposed within the irradiation chamber 16 are a left stage 58, a center stage 60, and a right stage 62, each of which includes a plurality of steps 64. The left stage 58 and center stage 60 define a left irradiation



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chamber 66 while the right stage 62 and center stage 60 define a right irradiation chamber 68. A cell holder 70, shown in phantom in Fig. 2 and in detail in Fig. 4, may be disposed within each of left irradiation chamber 66 and right irradiation chamber 68. The cell holder 70 includes a peripheral step 72 that is designed to allow a cell holder 70 to be supported upon complementary steps 64 of left stage 58 and center stage 60, and center stage 60 and right stage 62, respectively. As shown in Fig. 4, each cell holder 70 also includes a central bore 74 to allow the passage therethrough of ultraviolet light from the lamps 40 and an annular step 76 which is designed to support a lens cell 52 in a manner described below.

15

As shown in Fig. 6, each lens cell 52 includes opposed mold members 78, separated by an annular gasket 80 to define a lens molding cavity 82. The opposed mold members 78 and the annular gasket 80 may be selected in a manner to produce a lens having a desired diopter.

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The mold members 78, preferably, are formed of any suitable material that will permit rays of ultraviolet light to pass therethrough. The mold members 78, preferably, are formed of glass. Each mold member 78 has an outer peripheral surface 84 and a pair of opposed surfaces 86 and 88 with the surfaces 86 and 88 being precision ground. Preferably the mold members 78 have desirable ultraviolet light transmission characteristics and both the casting surface 86 and non-casting surface 88 preferably have no surface aberrations, waves, scratches or other defects as these may be reproduced in the finished lens.

30

As noted above, the mold members 78 are adapted to be held in spaced apart relation to define a lens molding

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cavity 82 between the facing surfaces 86 thereof. The mold members 78 are held in a spaced apart relation by a T-shaped flexible annular gasket 80 that seals the lens molding cavity 82 from the exterior of the mold

5 members 78. In use, the gasket 80 is supported on the annular step 76 of the cell holder 70.

In this manner, in the embodiment of the present invention that is illustrated in Fig. 6 the upper or back

10 mold member 90 has a convex inner surface 86 while the lower or front mold member 92 has a concave inner surface 86 so that the resulting lens molding cavity 82 is shaped to form a lens with a desired configuration. Thus, by selecting the mold members 78 with a desired

15 surface 86, lenses with different characteristics, such as focal lengths, may be made by the apparatus 10. Such techniques are well known to those skilled in the art, and will therefore not be further discussed.

20 Rays of ultraviolet light emanating from lamps 40 pass through the mold members 78 and act on a lens forming material disposed in the mold cavity 82 in a manner discussed below so as to form a lens. As noted above, the rays of ultraviolet light pass through a

25 suitable filter 54 or 56 to impinge upon the lens cell 52.

The mold members 78, preferably, are formed from a material that will not allow ultraviolet radiation having

30 a wavelength below approximately 300 nm to pass therethrough. Suitable materials are Schott Crown, S-1 or S-3 glass manufactured and sold by Schott Optical Glass Inc., of Duryea, Pennsylvania or Corning 8092 glass sold by Corning Glass of Corning, New York.

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The annular gasket 80 may be formed of vinyl material that exhibits good lip finish and maintains

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sufficient flexibility at conditions throughout the lens curing process. In a preferred embodiment, the annular gasket 80 is formed of silicone rubber material such as GE SE6035 which is commercially available from General Electric. In another preferred embodiment, the annular gasket 80 is formed of copolymers of ethylene and vinyl acetate which are commercially available from E. I. DuPont de Nemours & Co. under the trade name ELVAX®. Preferred ELVAX® resins are ELVAX® 350 having a melt index of 17.3-20.9 dg/min and a vinyl acetate content of 24.3-25.7 wt. %, ELVAX® 250 having a melt index of 22.0-28.0 dg/min and a vinyl acetate content of 27.2-28.8 wt. %, ELVAX® 240 having a melt index of 38.0-48.0 dg/min and a vinyl acetate content of 27.2-28.8 wt. %, and ELVAX® 150 having a melt index of 38.0-48.0 dg/min and a vinyl acetate content of 32.0-34.0 wt. %. Regardless of the particular material, the gaskets 80 may be prepared by conventional injection molding or compression molding techniques which are well-known by those of ordinary skill in the art.

As shown in phantom in Fig. 2, in section in Fig. 3, and in detail in Fig. 5, an upper and lower air distribution device 94 is disposed in each of left irradiation chamber 66 and right irradiation chamber 68. Each air distribution device 94 is connected to a pipe 12. As shown in Fig. 5, each air distribution device 94 includes a plenum portion 95 and a cylindrical opening 96 having orifices 98 disposed therein to allow for the expulsion of air from the air distribution device 94. The diameter of the orifices 98 varies around the circumference of cylindrical opening 96 preferably reaching a maximum when directly opposite the plenum portion 95 of air distribution device 94 and preferably reaching a minimum immediately adjacent the plenum portion 95. In addition, the orifices 98 are designed to blow air toward a lens cell 52 that may be disposed in a

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lens cell holder 70 and installed in left irradiation chamber 66 or right irradiation chamber 68.

5 In operation, the apparatus of the present invention may be appropriately configured for the production of positive lenses which are relatively thick at the center or negative lenses which are relatively thick at the edge. To reduce the likelihood of premature release, the relatively thick portions of a lens preferably are  
10 polymerized at a faster rate than the relatively thin portions of a lens.

The rate of polymerization taking place at various portions of a lens may be controlled by varying the  
15 relative intensity of ultraviolet light incident upon particular portions of a lens. The rate of polymerization taking place at various portions of a lens may also be controlled by directing air across the mold members 78 to cool the lens cell 52.

20

For positive lenses the intensity of incident ultraviolet light, preferably, is reduced at the edge portion of the lens so that the thicker center portion of the lens polymerizes faster than the thinner edge portion  
25 of the lens. Conversely, for a negative lens, the intensity of incident ultraviolet light, preferably, is reduced at the center portion of the lens so that the thicker edge portion of the lens polymerizes faster than the thinner center portion of the lens. For either a  
30 positive lens or a negative lens, air may be directed across the faces of the mold members 78 to cool the lens cell 52. As the overall intensity of incident ultraviolet light is increased, more cooling is needed which can be accomplished by either or both of increasing  
35 the velocity of the air and reducing the temperature of the air.

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It is well known by those of ordinary skill in the art that lens forming materials having utility in the present invention tend to shrink as they cure. If the relatively thin portion of a lens is allowed to  
5 polymerize before the relatively thick portion, the relatively thin portion will tend to be rigid at the time the relatively thick portion cures and shrinks and the lens will either release prematurely from or crack the mold members 78. Accordingly, when the relative  
10 intensity of ultraviolet light incident upon the edge portion of a positive lens is reduced relative to the center portion, the center portion polymerizes faster and shrinks before the edge portion is rigid so that the shrinkage is more uniform. Conversely, when the relative  
15 intensity of ultraviolet light incident upon the center portion of a negative lens is reduced relative to the edge portion, the edge portion polymerizes faster and shrinks before the center becomes rigid so that the shrinkage is more uniform.

20

According to the present invention, the variation of the relative intensity of ultraviolet light incident upon a lens may be accomplished in a variety of ways. According to one method, in the case of a positive lens,  
25 a ring of opaque material may be placed between the lamps 40 and the lens cell 52 so that the incident ultraviolet light falls mainly on the thicker center portion of the lens. Conversely, for a negative lens, a disk of opaque material may be placed between the  
30 lamps 40 and the lens cell 52 so that the incident ultraviolet light falls mainly on the edge portion of the lens.

According to another method, in the case of a  
35 negative lens, a sheet material having a variable degree of opacity ranging from opaque at a central portion to transparent at a radial outer portion is disposed between

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the lamps 40 and the lens cell 52. Conversely, for a positive lens, a sheet material having a variable degree of opacity ranging from transparent at a central portion to opaque at a radial outer portion is disposed between  
5 the lamps 40 and the lens cell 52.

According to still another method, a plurality of ultraviolet-light absorbing geometric or random shapes are printed and arranged on a sheet material. In the  
10 case of a positive lens, the density of the shapes is greatest at a radial outer portion while the density of the shapes is smallest at a central portion of the pattern. Conversely, in the case of a negative lens, the  
15 density of the shapes is smallest at a radial outer portion while the density of the shapes is greatest at a central portion of the pattern.

Those of ordinary skill in the art will recognize that there are a wide variety of techniques other than  
20 those enumerated above for varying the intensity of the ultraviolet light incident upon the opposed mold members 78.

The intensity of the incident light has been  
25 measured and determined to be approximately 3.0 to 5.0 milliwatts per square centimeter ( $\text{mW}/\text{cm}^2$ ) prior to passing through either the upper light filter 54 or the lower light filter 56 and the total intensity at the thickest  
30 part of the lens ranges from 0.6 to 2.0  $\text{mW}/\text{cm}^2$  while the intensity at the thinnest portion of the lens ranges from 0.1 to 1.5  $\text{mW}/\text{cm}^2$ . It has also been determined that the overall light intensity incident on the lens cell 52 has  
35 less of an impact on the final product than the relative light intensity incident upon the thick or thin portions of the lens so long as the lens cell 52 is sufficiently cooled to reduce the polymerization rate to an acceptable level.

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According to the present invention, it has been determined that the finished power of an ultraviolet light polymerized lens may be controlled by manipulating the distribution of the incident ultraviolet light striking the opposed mold members 78. For instance, for an identical combination of mold members 78 and gasket 80, the focusing power of the produced lens may be increased or decreased by changing the pattern of intensity of ultraviolet light across the lens mold cavity 82 or the faces of the opposed mold members 78.

As the lens forming material begins to cure, it passes through a gel state, the pattern of which within the lens cell 52 leads to the proper distribution of internal stresses generated later in the cure when the lens forming material begins to shrink.

As the lens forming material shrinks during the cure, the opposed mold members 78 will flex as a result of the different amounts of shrinkage between the relatively thick and the relatively thin portions of the lens. When a negative lens, for example, is cured, the upper or back mold member 90 will flatten and the lower or front mold member 92 will steepen with most of the flexing occurring in the lower or front mold member 92. Conversely, with a positive lens, the upper or back mold member 90 will steepen and the lower or front mold member 92 will flatten with most of the flexing occurring in the upper or back mold member 90.

By varying the intensity of the ultraviolet light between the relatively thin and the relatively thick portions of the lens in the lens forming cavity 82, it is possible to create more or less total flexing. Those light conditions which result in less flexing will minimize the possibility of premature release.

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The initial curvature of the opposed mold members 78 and the center thickness of the lens produced can be used to compute the theoretical or predicted power of the lens. The ultraviolet light conditions can be  
5 manipulated to alter the power of the lens to be more or less than predicted. For example, when a disk of opaque material is positioned between the lower lamp chamber 18 and the lens cell 52, less total flexure is observed. The greater the diameter of the disk of opaque material,  
10 the more negative (-) power the resultant lens will exhibit.

When the lenses cured by the ultraviolet light are removed from the opposed mold members 78, they are under  
15 a stressed condition. It has been determined that the power of the lens can be brought to a final resting power, by subjecting the lenses to a post-curing heat treatment to relieve the internal stresses developed during the cure and cause the curvature of the front and  
20 the back of the lens to shift. Typically, the lenses are cured by the ultraviolet light in about 10-30 minutes (preferably about 15 minutes). The post-curing heat treatment is conducted at approximately 85-120°C for approximately 5-15 minutes. Preferably, the post-curing  
25 heat treatment is conducted at 100-110°C for approximately 10 minutes. Prior to the post-cure, the lenses generally have a lower power than the final resting power. The post-curing heat treatment reduces yellowing of the lens and reduces stress in the lens to  
30 alter the power thereof to a final power. The post-curing heat treatment can be conducted in a conventional convection oven or any other suitable device.

35 According to the present invention, the ultraviolet lamps 40 preferably are maintained at a temperature at which the lamps 40 deliver maximum output. The lamps 40,



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preferably, are cooled because the intensity of the light produced by the lamps 40 fluctuates when the lamps 40 are allowed to overheat. In the apparatus of the present invention depicted in Fig. 2, the cooling of the lamps 40 is accomplished by sucking ambient air into the upper lamp chamber 14 and lower lamp chamber 18 through vent 32, vent chambers 34 and openings 36 by means of exhaust fans 44 and 46, respectively. Excessive cooling of the lamps 40 should be avoided, however, as the intensity of the light produced by the lamps 40 is reduced when the lamps 40 are cooled to an excessive degree.

As noted above, according to the present invention, the lens cell 52, preferably, is cooled during curing of the lens forming material as the overall intensity of the incident ultraviolet light is increased. Cooling of the lens cell 52 generally reduces the likelihood of premature release by slowing the reaction and improving adhesion. There are also improvements in the optical quality, stress characteristics and impact resistance of the lens. Cooling of the lens cell 52, preferably, is accomplished by blowing air across the lens cell 52. The air preferably has a temperature ranging between 15 and 85°F (about -9.4°C to 29.4°C) to allow for a curing time of between 30 and 10 minutes. The air distribution devices 94 depicted in Fig. 5 have been found to be particularly advantageous as they are specifically designed to direct air directly across the surface of the opposed mold members 78. After passing across the surface of the opposed mold members 78, the air emanating from the air distribution devices 94 is vented through vents 33. Alternately the air emanating from the air distribution devices 94 may be recycled back to an air cooler 312, such as is shown in Figure 9.

The lens cell 52 may also be cooled by disposing the lens cell in a liquid cooling bath.

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The opposed mold members 78, preferably, are thoroughly cleaned between each curing run as any dirt or other impurity on the mold members 78 may cause premature release. The mold members 78 are cleaned by any  
5 conventional means well known to those of ordinary skill in the art such as with a domestic cleaning product i.e. Mr. Clean® available from Proctor and Gamble. Those of ordinary skill in the art will recognize, however, that many other techniques may also be used for cleaning the  
10 mold members 78.

Yellowing of the finished lens may be related to the monomer composition, the identity of the photoinitiator and the concentration of the photoinitiator.  
15

When casting a lens, particularly a positive lens that is thick in the center, cracking may be a problem. Addition polymerization reactions, including  
photochemical addition polymerization reactions, are  
20 exothermic. During the process, a large temperature gradient may build up and the resulting stress may cause the lens to crack.

When the polymerization reaction proceeds too  
25 rapidly, heat buildup inside the system which leads to cracking is inevitable. The likelihood of cracking increases as the temperature difference between the center of the lens forming material and room temperature increases. During the polymerization process, several  
30 forces tending to crack the lens, such as shrinkage, adhesion, and thermal gradients, are at work. Other forces tending to crack the lens may occur when the irradiation is stopped and the lens is cooled, especially if the lens cell 52 is allowed to cool too quickly.

35

The formation of optical distortions usually occurs during the early stages of the polymerization reaction

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during the transformation of the lens forming composition from the liquid to the gel state. Once patterns leading to optical distortions form they are difficult to eliminate. When gelation occurs there is a rapid  
5 temperature rise. The exothermic polymerization step causes a temperature increase, which in turn causes an increase in the rate of polymerization, which causes a further increase in temperature. If the heat exchange with the surroundings is not sufficient enough there will  
10 be a runaway situation that leads to premature release, the appearance of thermally caused striations and even breakage. Since the rate of polymerization increases rapidly at the gelation point, this is an important phase of the reaction.

15

Accordingly, it is preferred that the reaction process be smooth and not too fast but not too slow. Heat is preferably not generated by the process so fast that it cannot be exchanged with the surroundings. The  
20 incident ultraviolet light intensity preferably is adjusted to allow the reaction to proceed at a desired rate. It is also preferred that the seal between the annular gasket 80 and the opposed mold members 78 is as complete as possible.

25

Factors that have been found to lead to the production of lenses that are free from optical distortions are (1) achieving a good seal between the annular gasket 80 and the opposed mold members 78; (2)  
30 using mold members 78 having surfaces that are free from defects; (3) using a formulation having an appropriate type and concentration of photoinitiator that will produce a reasonable rate of temperature rise; and (4) using a homogeneous formulation. Preferably, these  
35 conditions are optimized.

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Premature release of the lens from the mold will result in an incompletely cured lens and the production of lens defects. Factors that contribute to premature release are (1) a poorly assembled lens cell 52; (2) the  
5 presence of air bubbles around the sample edges; (3) imperfection in gasket lip or mold edge; (4) inappropriate formulation; (5) uncontrolled temperature rise; and (6) high or nonuniform shrinkage. Preferably, these conditions are minimized.

10

Premature release may also occur when the opposed mold members 78 are held too rigidly by the annular gasket 80. Preferably, there is sufficient flexibility in the annular gasket 80 to permit the opposed mold  
15 members 78 to follow the lens as it shrinks. Indeed, the lens must be allowed to shrink in diameter slightly as well as in thickness. The use of an annular gasket 80 that has a reduced degree of stickiness with the lens during and after curing is therefore desirable.

20

In a preferred technique for filling the lens molding cavity 82, the annular gasket 80 is placed on a concave or front mold member 92 and a convex or back mold member 90 is moved into place. The annular gasket 80 is  
25 then pulled away from the edge of the back mold member 90 at the uppermost point and a lens forming composition is injected into the lens molding cavity 82 until a small amount of the lens forming composition is forced out around the edge. The excess is then removed, preferably,  
30 by vacuum. Excess liquid that is not removed could spill over the face of the back mold member 90 and cause optical distortion in the finished lens.

Despite the above problems, the advantages offered  
35 by the radiation cured lens molding system clearly outweigh the disadvantages. The advantages of a radiation cured system include a significant reduction in

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energy requirements, curing time and other problems normally associated with conventional thermal systems.

According to the present invention, the lens forming material can comprise any suitable liquid monomer or monomer mixture and any suitable photosensitive initiator. The lens forming material, preferably, does not include any component, other than a photoinitiator, that absorbs ultraviolet light having a wavelength in the range of 300 to 400 nm. The liquid lens forming material, preferably, is filtered for quality control and placed in the lens molding cavity 82 by pulling the annular gasket 80 away from one of the opposed mold members 78 and injecting the liquid lens forming material into the lens molding cavity 82. Once the lens molding cavity 82 is filled with such material, the annular gasket 80 is replaced into its sealing relation with the opposed mold members 78. The material can then be irradiated with ultraviolet light in the manner described above for a time period that is necessary to cure the lens forming material, preferably approximately 10 to approximately 30 minutes. The ultraviolet light entering the lens molding cavity 82 preferably has a wavelength in the range of approximately 300 nm. to approximately 400 nm.

Those skilled in the art will recognize that once the cured lens is removed from the lens molding cavity 82 by disassembling the opposed mold members 78, the lens can be further processed in a conventional manner, such as by grinding its peripheral edge.

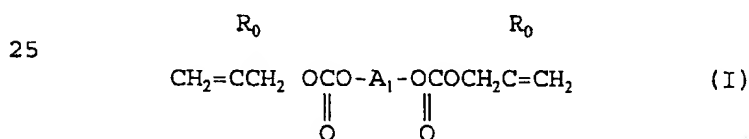
According to the present invention a polymerizable lens forming composition comprises an aromatic-containing bis(allyl carbonate)-functional monomer and at least one polyethylenic-functional monomer containing two ethylenically unsaturated groups selected from acrylyl.

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and methacrylyl. In a preferred embodiment, the composition further comprises a suitable photoinitiator. In other preferred embodiments, the composition may include one or more polyethylenic-functional monomers  
 5 containing three ethylenically unsaturated groups selected from acrylyl and methacrylyl, and a dye.

Aromatic-containing bis(allyl carbonate)-functional monomers which can be utilized in the practice of the  
 10 present invention are bis(allyl carbonates) of dihydroxy aromatic-containing material. The dihydroxy aromatic-containing material from which the monomer is derived may be one or more dihydroxy aromatic-containing compounds. Preferably the hydroxyl groups are attached  
 15 directly to nuclear aromatic carbon atoms of the dihydroxy aromatic-containing compounds. The monomers are themselves known and can be prepared by procedures well known in the art.

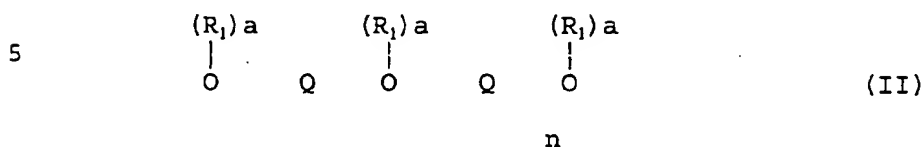
20 The aromatic-containing bis(allyl carbonate)-functional monomers can be represented by the formula:



30 in which A<sub>1</sub> is the divalent radical derived from the dihydroxy aromatic-containing material and each R<sub>0</sub> is independently hydrogen, halo, or a C<sub>1</sub>-C<sub>4</sub> alkyl group. The alkyl group is usually methyl or ethyl. Examples of R<sub>0</sub>  
 35 include hydrogen, chloro, bromo, fluoro, methyl, ethyl, n-propyl, isopropyl and n-butyl. Most commonly R<sub>0</sub> is hydrogen or methyl; hydrogen is preferred. A subclass of

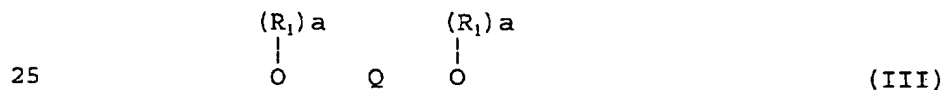
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the divalent radical  $A_1$  which is of particular usefulness is represented by the formula:



10 in which each  $R_1$  is independently alkyl containing from 1 to about 4 carbon atoms, phenyl, or halo; the average value of each  $a$  is independently in the range of from 0 to 4; each  $Q$  is independently oxy, sulfonyl, alkanediyl  
 15 having from 2 to about 4 carbon atoms, or alkylidene having from 1 to about 4 carbon atoms; and the average value of  $n$  is in the range of from 0 to about 3. Preferably  $Q$  is methylethylidene, viz., isopropylidene.

20 Preferably the value of  $n$  is zero, in which case  $A_1$  is represented by the formula:

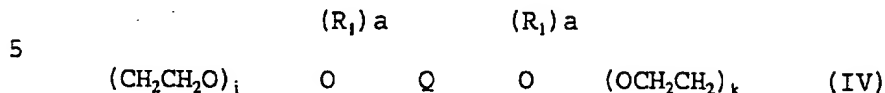


in which each  $R_1$ , each  $a$ , and  $Q$  are as discussed in respect of Formula II. Preferably the two free bonds are  
 30 both in the ortho or para positions. The para positions are especially preferred.

The dihydroxy aromatic-containing compounds from which  $A_1$  is derived may also be polyol-functional chain  
 35 extended compounds. Examples of such compounds include alkaline oxide extended bisphenols. Typically the alkaline oxide employed is ethylene oxide, propylene oxide, or mixtures thereof. By way of exemplification, when para, para-bisphenols are chain extended with

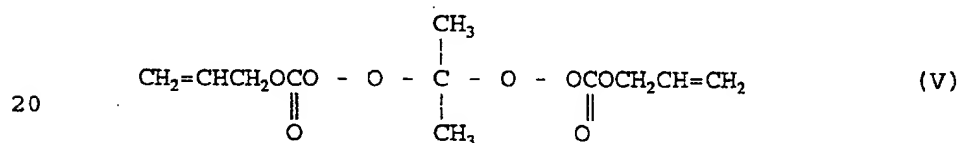
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ethylene oxide, the bivalent radical A, may often be represented by the formula:



where each  $R_1$ , each  $a$ , and  $Q$  are as discussed in respect of Formula II, and the average values of  $j$  and  $k$  are each independently in the range of from about 1 to about 4.

The preferred aromatic-containing bis(allyl carbonate)-functional monomer is represented by the formula:



and is commonly known as bisphenol A bis(allyl carbonate).

A wide variety of compounds may be used as the polyethylenic functional monomer containing two or three ethylenically unsaturated groups. The preferred polyethylenic functional compounds containing two or three ethylenically unsaturated groups may be generally described as the acrylic acid esters and the methacrylic acid esters of aliphatic polyhydric alcohols, such as, for example, the di- and triacrylates and the di- and trimethacrylates of ethylene glycol, triethylene glycol, tetraethylene glycol, tetramethylene glycol, glycidyl, diethyleneglycol, butyleneglycol, propyleneglycol, pentanediol, hexanediol, trimethylolpropane, and tripropyleneglycol. Examples of specific suitable polyethylenic - functional monomers containing two or three ethylenically unsaturated groups include



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trimethylolpropanetriacrylate (TMPTA), tetraethylene glycol diacrylate (TTEGDA), tripropylene glycol diacrylate (TRPGDA), 1,6 hexanedioldimethacrylate (HDDMA), and hexanedioldiacrylate (HDDA).

5

In general, a photoinitiator for initiating the polymerization of the lens forming composition of the present invention, preferably, exhibits an ultraviolet absorption spectrum over the 300-400 nm range. High absorptivity of a photoinitiator in this range, however, is not desirable, especially when casting a thick lens. The following are examples of illustrative photoinitiator compounds within the scope of the invention: methyl benzoylformate, 2-hydroxy-2-methyl-1-phenylpropan-1-one, 10 1-hydroxycyclohexyl phenyl ketone, 2,2-di-sec-butoxyacetophenone, 2,2-diethoxyacetophenone, 2,2-diethoxy-2-phenyl-acetophenone, 2,2-dimethoxy-2-phenyl-acetophenone, benzoin methyl ether, benzoin isobutyl ether, benzoin, benzil, benzyl disulfide, 15 2,4-dihydroxybenzophenone, benzylideneacetophenone, benzophenone and acetophenone. Preferred photoinitiator compounds are 1-hydroxycyclohexyl phenyl ketone (which is commercially available from Ciba-Geigy as Irgacure 184), methyl benzoylformate (which is commercially available 20 from Polysciences, Inc.), or mixtures thereof.

25

Methyl benzoylformate is a generally preferred photoinitiator because it tends to provide a slower rate of polymerization. The slower rate of polymerization 30 tends to prevent excessive heat buildup (and resultant cracking of the lens) during polymerization. In addition, it is relatively easy to mix liquid methyl benzoylformate (which is liquid at ambient temperatures) with many acrylates, diacrylates, and allyl carbonate 35 compounds to form a lens forming composition. The lenses produced with the methyl benzoylformate photoinitiator

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tend to exhibit more favorable stress patterns and uniformity.

5 A strongly absorbing photoinitiator will absorb most of the incident light in the first millimeter of lens thickness, causing rapid polymerization in that region. The remaining light will produce a much lower rate of polymerization below this depth and will result in a lens that has visible distortions. An ideal photoinitiator 10 will exhibit high activity, but will have a lower extinction coefficient in the useful range. A lower extinction coefficient of photoinitiators at longer wavelengths tends to allow the ultraviolet radiation to penetrate deeper into the reaction system. This deeper 15 penetration of the ultraviolet radiation allows photoinitiator radicals to form uniformly throughout the sample and provide excellent overall cure. Since the sample can be irradiated from both top and bottom, a system in which appreciable light reaches the center of 20 the thickest portion of the lens is preferred. The photoinitiator solubility and compatibility with the monomer system is also an important requirement.

25 An additional consideration is the effect of the photoinitiator fragments in the finished polymer. Some photoinitiators generate fragments that impart a yellow color to the finished lens. Although such lenses actually absorb very little visible light, they are cosmetically undesirable.

30 Photoinitiators are often very system specific so that photoinitiators that are efficient in one system may function poorly in another. In addition, the initiator concentration to a large extent is dependent on the 35 incident light intensity and the monomer composition. The identity of the initiator and its concentration are important for any particular formulation. A

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concentration of initiator that is too high tends to lead to cracking and yellowing of the lens. Concentrations of initiator that are too low tend to lead to incomplete polymerization and a soft material.

5

Dyes and/or pigments are optional materials that may be present when high transmission of light is not necessary.

10

The listing of optional ingredients discussed above is by no means exhaustive. These and other ingredients may be employed in their customary amounts for their customary purposes so long as they do not seriously interfere with good polymer formulating practice.

15

According to a preferred embodiment of the present invention, the preferred aromatic-containing bis(allyl carbonate) functional monomer, bisphenol A bis(allyl carbonate) is admixed with one or more faster reacting polyethylenic functional monomers containing two acrylate or methacrylate groups such as 1,6 hexanediol dimethacrylate (HDDMA), 1,6 hexanediol diacrylate (HDDA), tetraethylene glycol diacrylate (TTEGDA), and tripropylene glycol diacrylate (TRPGDA) and optionally a polyethylenic functional monomer containing three acrylate groups such as trimethylolpropane triacrylate (TMPTA). Generally, compounds containing acrylate groups polymerize much faster than those containing allyl groups.

30

The lamps 40 generate an intensity at the lamp surface of approximately 4.0 to 7.0 mW/cm<sup>2</sup> of ultraviolet light having wavelengths between 300 and 400 nm, which light is very uniformly distributed without any sharp discontinuities throughout the reaction process. Such bulbs are commercially available from Sylvania under the trade designation Sylvania Fluorescent (F158T/2052) or

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Sylvania Fluorescent (F258T8/350BL/18") GTE. As noted above, ultraviolet light having wavelengths between 300 and 400 nm is preferred because the photoinitiators according to the present invention, preferably, absorb most efficiently at this wavelength and the mold members 78, preferably, allow maximum transmission at this wavelength.

It is preferred that there be no sharp intensity gradients of ultraviolet radiation either horizontally or vertically through the lens composition during the curing process. Sharp intensity gradients through the lens may lead to defects in the finished lens.

According to one embodiment of the present invention, the liquid lens forming composition includes bisphenol A bis(allyl carbonate) in place of DEG-BAC. The bisphenol A bis(allyl-carbonate) monomer has a higher refractive index than DEG-BAC which allows the production of thinner lenses which is important with relatively thick positive or negative lenses. The bisphenol A bis(allyl-carbonate) monomer is commercially available from PPG Industries under the trade name HIRI I or CR-73. Lenses made from this product sometimes have a very slight, barely detectable, degree of yellowing. A small amount of a blue dye consisting of 9, 10-anthracenedione, 1-hydroxy-4-[(4-methylphenyl)amino] available as Thermoplast Blue 684 from BASF Wyandotte Corp. is preferably added to the composition to counteract the yellowing. In addition, the yellowing tends to disappear if the lens is subjected to the above-described post-cure heat treatment. Moreover, if not post-cured the yellowing tends to disappear at ambient temperature after approximately 2 months.

According to a preferred embodiment, the composition of the present invention includes (a) bisphenol

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A-bis(allyl carbonate); (b) at least one of HDDMA, TTEGDA and TRPGDA; and (c) a photoinitiator. According to this embodiment the composition may also include one or both of TMPTA and a dye.

5

According to another preferred embodiment, the composition of the present invention includes (a) up to 70 percent by weight of bisphenol A bis(allyl carbonate); (b) up to 100 percent by weight of HDDMA; (c) up to 100 percent by weight of TTEGDA; (d) up to 100 percent by weight of TRPGDA; and (e) up to 100 percent by weight of TMPTA. Preferably, the composition further comprises (f) up to about 1.0 percent by weight of 1-hydroxycyclohexylphenyl ketone; and (g) up to about 1.2 percent by weight of methyl benzoylformate. Preferably the composition further comprises (h) up to about 1.0 parts per million (ppm) of 9,10-anthracenedione, 1-hydroxy-4-[(4-methylphenyl)amino].

20 According to still another preferred embodiment, the composition of the present invention includes (a) about 15.0 to about 25.0 percent by weight of bisphenol A bis(allyl-carbonate); (b) about 8.0 to about 14.0 percent by weight of HDDMA; (c) about 15.0 to about 25.0 percent by weight of TTEGDA; (d) about 17.0 to about 37.0 percent by weight of TRPGDA; and (e) about 15.0 to about 25.0 percent by weight of TMPTA. The composition may also include (f) about 0.003 to about 0.04 percent by weight of 1-hydroxycyclohexylphenyl ketone, (g) about 0.015 to about 0.05 percent by weight of methyl benzoylformate, and (h) about 0.16 to about 0.20 ppm of 9,10-anthracenedione, 1-hydroxy-4-[(4-methylphenyl)amino].

35 According to a further preferred embodiment, the composition includes 17.0% by weight of bisphenol A bis(allyl carbonate), 10.0% by weight of HDDMA, 21.0% by

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weight of TTEGDA, 32.0% by weight of TRPGDA, and 20.0% by weight of TMPTA. The composition may also include 0.0095% by weight of 1-hydroxycyclohexylphenyl ketone, 0.0356% by weight of methyl benzoylformate, and 0.16 ppm of 9,10-anthracenedione, 1-hydroxy-4-[(4-methylphenyl)amino].

As discussed above, bisphenol A bis(allyl carbonate) has a higher refractive index than DEG-BAC and thus allows the production of thinner lenses when compared to DEG-BAC lenses.

TTEGDA, available from Sartomer and Radcure, is a diacrylate monomer that, preferably, is included in the composition because it is a fast polymerizing monomer that reduces yellowing and yields a very clear product. If too much TTEGDA is included in the most preferred composition, i.e. greater than about 25% by weight, however, the finished lens may be prone to cracking and may be too flexible as this material softens at temperatures above 40°C. If TTEGDA is excluded altogether, the finished lens may to be brittle.

HDDMA, available from Sartomer, is a dimethacrylate monomer that has a very stiff backbone between the two methacrylate groups. HDDMA, preferably, is included in the composition because it yields a stiffer polymer and increases the hardness and strength of the finished lens. This material is quite compatible with the bisphenol A bis(allyl carbonate) monomer. HDDMA contributes to high temperature stiffness, polymer clarity and speed of polymerization.

TRPGDA, available from Sartomer and Radcure, is a diacrylate monomer that, preferably, is included in the composition because it provides good strength and

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hardness without adding brittleness to the finished lens.  
This material is also stiffer than TTEGDA.

TMPTA, available from Sartomer and Radcure, is a  
5 triacrylate monomer that, preferably, is included in the  
composition because it provides more crosslinking in the  
finished lens than the difunctional monomers. TMPTA has  
a shorter backbone than TTEGDA and increases the high  
temperature stiffness and hardness of the finished lens.  
10 Moreover, this material contributes to the prevention of  
optical distortions in the finished lens. TMPTA also  
contributes to high shrinkage during polymerization. The  
inclusion of too much of this material in the most  
preferred composition may make the finished lens too  
15 brittle.

Certain of the monomers that are preferably utilized  
in the composition of the present invention, such as  
TTEGDA, TRPGDA and TMPTA, include impurities and have a  
20 yellow color in certain of their commercially available  
forms. The yellow color of these monomers is preferably  
reduced or removed by passing them through a column of  
alumina (basic) which includes aluminum oxide powder -  
basic. After passage through the alumina column, the  
25 monomers absorb almost no ultraviolet light. Also after  
passage through the alumina column differences between  
monomers obtained from different sources are  
substantially eliminated. It is preferred, however, that  
the monomers be obtained from a source which provides the  
30 monomers with the least amount of impurities contained  
therein. The composition preferably is filtered prior to  
polymerization thereof to remove suspended particles.

The composition of the present invention,  
35 preferably, may be prepared according to the following  
protocol. Appropriate amounts of HDDMA, TTEGDA, TMPTA  
and TRPGDA are mixed and stirred thoroughly, preferably

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with a glass rod. The acrylate/methacrylate mixture may then be passed through a purification column.

5 A suitable purification column may be disposed within a glass column having a fitted glass disk above a teflon stopcock and having a top reservoir with a capacity of approximately 500 ml and a body with a diameter of 22 mm and a length of about 47 cm. The column may be prepared by placing on the fitted glass  
10 disk approximately 35 g. of activated alumina (basic), available from ALFA Products, Johnson Matthey, Danvers, MA in a 60 mesh form or from Aldrich in a 150 mesh form. Approximately 10 g. of an inhibitor remover (hydroquinone/methylester remover) available as HR-4 from  
15 Scientific Polymer Products, Inc., Ontario, NY then may be placed on top of the alumina and, finally, approximately 35 g. of activated alumina (basic) may be placed on top of the inhibitor remover.

20 Approximately 600 g. of the acrylate/methacrylate mixture may then be added above the column packing. An overpressure of 2-3 psi may then be applied to the top of the column resulting in a flow rate of approximately 30 to 38 grams per hour. Parafilm may be used to cover the  
25 junction of the column tip and the receiving bottle to prevent the infiltration of dust and water vapor. The acrylate/methacrylate mixture, preferably, may be received in a container that is opaque to ultraviolet radiation.

30

An appropriate amount of bisphenol A bis(allyl carbonate) may then be added to the acrylate/methacrylate mixture to prepare the final monomer mixture.

35 An appropriate amount of a photoinitiator may then be added to the final monomer mixture. The final monomer mixture, with or without photoinitiator, may then be



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stored in a container that is opaque to ultraviolet radiation.

5 An appropriate amount of a dye may also be added to the final monomer mixture, with or without photoinitiator.

10 After edging, the ultraviolet light cured lenses of the present invention demonstrate excellent organic solvent resistance to acetone, methylethyl ketone, and alcohols.

Premature release may occur if the temperature rise of the lens forming composition is uncontrolled.

15 Premature release may also occur if the opposed mold members 78 are held too rigidly by the annular gasket 80. There is preferably sufficient flexibility in the gaskets 80 to permit the mold members 78 to follow the lens as it shrinks. Insufficient sealing, unsuitable gasket

20 material and/or a small residual amount of uncured material have also been found to contribute to premature release failures.

For best results, both the casting surfaces 86 and

25 non-casting surfaces 88 of the mold members 78 are finished to optical quality. For instance, a wave on the non-casting surface 88 may be reproduced in the finished lens as a result of the distortion of the incident light.

30 Mold markings cause differential light intensity conditions under the marking, even when the mark is on the non-casting surface 88 of the mold members 78. The fully exposed region of the lens will tend to be harder, and the lens may have stresses because of this. The

35 portion of the lens under the mark will also tend to be weaker at the end of the curing period. This effect has

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been observed and may cause premature release or induce cracking.

5       Mold defects at the edges interfere with the sealing conditions and frequently induce premature release.

10       According to the present invention, plastic lenses may be produced by irradiating the lens forming material with ultraviolet light that is prevented from passing through the faces of the opposed mold members 78 and instead passes through the transparent or translucent wall of annular gasket 80 of the lens cell 52. By irradiating in this manner, the thicker edge portion of a negative lens receives a higher level of light intensity  
15       than the thinner center portion since the light intensity drops as it passes through the deeper layers of the lens material and glass molds. This method has a desirable advantage of allowing the application of clamping pressure to the front and back molds, which is useful in  
20       controlling premature release. This technique will be referred to as through-the-gasket irradiation. Referring to Fig. 7, apparatus 100 is shown for carrying out through-the-gasket irradiation. Apparatus 100 includes lamp chamber 102 having a plurality of ultraviolet light  
25       generating lamps 104 disposed therein. A lens cell 52 in accordance with Fig. 6 is suspended in lamp chamber 102. A cover 106 of opaque material is placed over the non-casting surface 88 of each mold member 78 of the lens cell 52. In this manner, ultraviolet light emanating  
30       from the plurality of lamps 104 that is incident upon the lens cell 52 acts upon the lens forming material disposed in the lens molding cavity 82 by passing through the outer wall 108 of the annular gasket 80. A spring-loaded clamp 110, preferably, may be used to apply compression  
35       pressure upon the opposed mold members 78 of the lens cell 52. The spring-loaded clamp, preferably, may be adjusted to exert variable pressure upon the opposed mold

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members 78. Moreover, opaque disks 106 may be disposed between the respective jaws of the clamp 110 and the mold members 78 to prevent scratching of the molds and to prevent light leakage through the mold.

5

An alternate technique for through-the-gasket irradiation is shown in Fig. 8. Referring to Fig. 8, apparatus 200 is shown for carrying out through-the-gasket irradiation. Apparatus 200 includes opposed lamp arrays 202. A lens cell 52 in accordance with Fig. 6 is placed on a turntable 204 disposed between opposed lamp arrays 202. An annular opaque stage 206 is disposed under the front mold member 92 and rests directly on turntable 204. A cap 208 of opaque material is disposed on the back mold member 90. A weight 210 may be disposed upon the back mold member 90 to exert sufficient clamping pressure to prevent premature release.

According to the through-the-gasket irradiation technique, the annular gaskets 80, preferably, are silicone gaskets. Through continued use, however, silicone gaskets tend to become too opaque to allow sufficient ultraviolet light to pass through the gasket to complete the polymerization of the lens forming material. In addition, gaskets having a frosty appearance were observed to yield good quality lenses while gaskets that were clear were observed to yield lenses with optical distortions.

30

The through-the-gasket irradiation techniques make it relatively easy to exert clamping pressure on the mold members 78. Pressure (up to 30 psi) may be applied to the mold members 78, preferably at or about the onset of gelation of the lens forming material, i.e. after the lens forming material is no longer liquid but before it becomes incompressible. At the beginning of the

35

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irradiation when the lens forming material is liquid, however, low clamping pressure (such as 2 lb.) may be applied to the mold members 78, which pressure is not so great that the lens forming material leaks between the gasket 80 and the edges of the mold members 78. These techniques also tend to make it easier to direct evenly distributed ultraviolet light to the lens forming material. The gasket 80 serves as a diffuser and prevents sharp intensity gradients that occur when light is passing through the mold and there is an irregularity in the mold. Since the edge of a lens receives a higher intensity of ultraviolet light than the center of the lens, the through-the-gasket technique, therefore, is quite beneficial for the production of negative lenses. Finally, since ultraviolet radiation does not pass through the mold members 78 according to this technique, metal molds which are more flexible (and which tend to exhibit enhanced heat transfer properties) than glass molds can be utilized.

As discussed above, the likelihood of premature release may be affected by a number of often interrelated factors. Factors such as improper mold cleaning, mold thickness, or gasket/mold design may contribute to premature release. Other factors that may contribute to premature release may include light intensity, the chemical formulations, and the amount and identity of the photoinitiator ("PI"). As discussed above, an additional factor related to premature release is the exothermic heat generated by the reaction.

It is believed that as the reaction proceeds, the heat generated tends to reduce the adhesion between the shrinking lens and the mold face. This reduction in adhesion tends to cause the lens to pull away from the mold. In high curvature (i.e. high power) lenses this problem tends to be even more pronounced because of two

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factors: (1) these lenses have more thickness and thus more material that is generating heat (which thus speeds up the reaction and generates more heat), and (2) these lenses have a greater thickness differential between the thick and thin portions of the lens, which tends to cause stress on the molds due to differential shrinkage. It is also possible that the temperatures generated relatively deep inside a thick lens may cause some vaporization of the monomer. The vaporized monomer may then migrate to the lens/mold interface, breaking the vacuum between the two.

Because of the problem of premature release, preferably high power lenses are cured to maintain adhesion to the molds. Preferably the molds flex and accommodate stress.

Preferably premature release is controlled by controlling the exothermic reaction heat. This heat is preferably controlled by directing cooling fluid such as air at the mold faces. Thus in a preferred embodiment the invention includes the following steps: (1) placing a polymerizable lens forming material in a mold cavity defined in part between a first mold member and a second mold member, (2) directing ultraviolet rays towards at least one of the first or second mold members, and (3) cooling the first mold member and the second mold member with a fluid. In a preferred embodiment the ultraviolet rays are directed towards the mold member(s) while the first and second mold members are cooled. The above steps may be carried out with an apparatus for making a plastic lens that includes: (1) a first mold member, (2) a second mold member spaced apart from the first mold member, the first and second mold members defining a mold cavity, (3) an ultraviolet light generator for generating and directing ultraviolet light toward at least one of the first and second mold members during use, (4) an

ultraviolet light filter disposed between the ultraviolet light generator and the first mold member, and between the ultraviolet light generator and the second mold member, and (5) a distributor for directing cooling fluid to the mold members during use.

Preferably both the first and second mold members are "directly" cooled by the fluid. That is, preferably the face of the first mold member and the face of the second mold member is cooled by directing fluid towards the face of both of the mold members. This "face" of the mold members is the outer mold surface that is not contacting either the gasket or the lens forming materials (see Fig. 6). The fluid may be directed at various angles towards the face of the mold members.

Generally less preferred results are achieved if only one (instead of both) of the mold members is directly cooled. It is believed that directly cooling only one of the mold members tends to result in less preferred lenses because doing so unevenly cools the lens material during curing. Thus preferably the first and second mold members are both substantially evenly exposed to the cooling fluid temperatures and flowrates.

Preferably fluid is directed from the edges of the mold member faces to the center of the mold member faces. In this manner the fluid that contacts the edges of the mold members is approximately the same temperature at all the edges of the mold members, and approximately the same at all radii from the center of the mold members (with some variances due to variances in the cavity thickness at certain radii). Thus substantially the same thicknesses of the lens material are subjected to fluid that is substantially the same temperature, resulting in a more even cooling of the lens material. Generally less favorable results are achieved if fluid is simply

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directed across the mold members since the fluid temperature and flow rate at the first edge contacted by the fluid may be somewhat different than the fluid temperature and flow rate at the second mold member edge. Specifically, if cooling fluid is passed over the lens forming material in one direction only, the side opposite the source of fluid tends to remain hotter because the fluid passing over it has picked up the heat from the first side.

10

Preferably the fluid is air at a temperature of less than 50°C. The fluid may be below 0°C, however in a preferred embodiment the fluid was at a temperature of between 0°C and less than 20°C, preferably about 0-15°C, more preferably about 0-10°C, more preferably still about 3-8°C. In one preferred embodiment the fluid temperature was about 5°C. As shown in Figure 9, a lens forming apparatus 300 for making a plastic lens may include a cooler 312 for supplying cool fluid to the apparatus 300 via conduit 314. The fluid may be supplied to the apparatus 300 and then discharged via conduit 320. The fluid discharged via conduit 320 may be vented via conduit 318 or it may alternately be recirculated via conduit 316 to the cooler 312. The cooler 312 preferably includes a Neslab CFT-50 water/antifreeze chiller (Newington, N.H., U.S.A.). A Neslab-built blower box designed for a minimum temperature of 3°C and 8 cubic feet (about 0.224 cubic meters) per minute of air per air distributor 94 was used with the chiller. The blower box included a heat exchanger coil through which chilled water was circulated, a blower, and a plenum-type arrangement for supplying air to the conduit 314.

If lenses are produced without any mold cooling, the temperature of the mold-lens assembly may rise to above 50°C. Low diopter lenses may be prepared in this fashion, but higher plus or minus diopter lenses may

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fail. Certain lenses may be made by controlling (e.g., cooling) the temperature of the lens material during cure with circulating uncooled fluid (i.e., fluid at ambient temperatures). The ambient fluid in these systems is  
5 directed towards the mold members in the same manner as described above. Circulating ambient temperature fluid permits manufacture of a wider range of prescriptions than manufacture of the lenses without any mold cooling at all. For instance, if the temperature of the  
10 circulating air is held at slightly less than room temperature (about 19°C), prescriptions from +2 to -3 diopter may be successfully cast. Higher diopeters, either + or -, often tend to fail without circulating cooled fluid.

15

Most polymerization factors are interrelated. The ideal temperature of polymerization is related to the diopter and thickness of the lens being cast. Thermal mass is a factor. Lower temperatures (below about 10°C)  
20 are preferred to cast higher + or - diopter lenses. These lower temperatures tend to permit an increase in photoinitiator concentration, which in turn may speed up the reaction and lower curing time.

25

Preventing premature release is also somewhat dependent upon the flowrates of cooling fluid, as well as its temperature. For instance, if the temperature of the cooling fluid is decreased it may also be possible to decrease the flowrate of cooling fluid. Similarly, the  
30 disadvantages of a higher temperature cooling fluid may be somewhat offset by higher flowrates of cooling fluid.

35

In one embodiment the air flow rates for a dual distributor system (i.e., an air distributor above and below the lens composition) are about 1-30 standard cubic feet (about 0.028 - 0.850 standard cubic meters) per minute per distributor, more preferably about 4-20 cubic



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feet (about 0.113-0.566 standard cubic meters) per minute per distributor, and more preferably still about 9-15 (about 0.255-0.423 standard cubic meters) cubic feet per minute per distributor. "Standard conditions," as used  
5 herein, means 60°F (about 15.556°C) and one atmosphere pressure (about 101.325 kilopascals).

In a preferred embodiment the fluid distributor 94 may include 30 substantially evenly spaced orifices 98  
10 disposed to allow fluid to be directed from the distributor 94 to the mold members. In a preferred embodiment the diameter of fifteen orifices 98 on the one-half of the cylindrical opening 96 closest the plenum portion 95 is about 1/4 inch (about 6.35 mm), and  
15 the cumulative volume flowrate of air through such orifices is estimated to be about 6.10 standard cubic feet (about 0.173 standard cubic meters) per minute. In the same embodiment the diameter of fifteen orifices 98 on one-half of the cylindrical opening 96 opposite the  
20 plenum portion 95 is about 5/16 inch (about 7.94 mm), and the cumulative volume flowrate of air through such orifices is estimated to be about 8.30 standard cubic feet (about 0.235 standard cubic meters) per minute. Thus the total flowrate for one distributor is estimated  
25 to be about 14.40 standard cubic feet (about 0.408 standard cubic meters) per minute, and the total flowrate for two distributors is estimated to be about 28.80 standard cubic feet (about 0.816 standard cubic meters) per minute.

30

In the same embodiment the edge of the orifices 98 in the cylindrical opening 96 are tapered out. In such case the cumulative flowrates for the 1/4 inch (6.35 mm) orifices 98 is estimated to be about 5.89 standard cubic  
35 feet (about 0.167 standard cubic meters) per minute, and the flowrate for the 5/16 inch (7.94 mm) orifices 98 is estimated to be about 7.02 standard cubic feet (about

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0.199 standard cubic meters) per minute. Thus the total flowrate for one distributor is estimated to be about 12.91 standard cubic feet (about 0.366 standard cubic meters) per minute, and the total flowrate for two  
5 distributors is estimated to be about 25.82 standard cubic feet (about 0.731 standard cubic meters) per minute.

In an alternate preferred embodiment the diameter of  
10 fifteen orifices 98 on the one-half of the cylindrical opening 96 closest to the plenum portion 95 are about 3/16 inch (about 4.76 mm), and the cumulative volume flowrate of air through such orifices is estimated to be about 3.47 standard cubic feet (about 0.98 standard cubic  
15 meters) per minute. In the same embodiment the diameter of fifteen orifices 98 on the one-half of the cylindrical opening 96 opposite the plenum portion 95 are about 1/4 inch (about 6.35 mm), and the cumulative volume flowrate of air through such orifices is estimated to be about  
20 6.17 standard cubic feet (about 0.175 standard cubic meters) per minute. Thus the total flowrate for one distributor is estimated to be about 9.64 standard cubic feet (about 0.273 standard cubic meters) per minute, and the total flowrate for two distributors is estimated to  
25 be about 19.28 standard cubic feet (about 0.546 standard cubic meters) per minute.

Actual flowrates through individual orifices 98 tended to vary. The flowrates through the orifices 98  
30 that were closest to or most opposite the plenum portion 95 of air distribution device 94 tended to have a flowrate that is greater than orifices in between these orifices. These higher flowrates varied up to approximately 1.2-2.5 times the flowrate of orifices that  
35 were in between the closest to and most opposite orifices.

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The above estimated flowrates for orifices 98 in a preferred embodiment were calculated using a bench model of air distributor 94 connected to air flowrate measuring devices. The air flowrates for the orifices 98 in the bench model were measured. The total air flowrate through the bench model distributor 94 was measured. The total air flowrate for a preferred embodiment distributor 94 was measured. The above flowrates were measured by measuring the average velocity across a cross-sectional area, and then multiplying such velocity by the cross-sectional area. The estimated flowrates for the preferred embodiment orifices 98 were obtained by the following equation:

$$P_o = B_o \times (P_A/B_A), \text{ where}$$

$P_o$  = estimated preferred embodiment orifices 98 flowrate,

$P_A$  = measured preferred embodiment distributor 94 flowrate,

$B_o$  = measured bench orifices 98 flowrate, and

$B_A$  = measured bench distributor 94 flowrate.

The thickness of the glass molds used to cast polymerized lenses may affect the lenses produced. A thinner mold tends to allow more efficient heat transfer between the polymerizing material and the cooling air, thus reducing the rate of premature release. In addition, a thinner mold tends to exhibit a greater propensity to flex. A thinner mold tends to flex during the relatively rapid differential shrinkage between the thick and thin portions of a polymerized lens, again reducing the incidence of premature release. In one embodiment the first or second mold members have a thickness less than about 5.0 mm, preferably about 1.0-5.0 mm, more preferably about 2.0-4.0 mm, and more still about 2.5-3.5 mm.

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Higher diopter ("D") lenses both have more mass (and so release more heat during the curing cycle) and also define a greater difference between their thick and thin portions than a lower diopter lens. Accordingly, for 74 mm diameter negative lenses stronger than about -2.00 D, it is preferably to reduce the thickness of the front (concave) mold to less than 4 mm and preferably to between 3.0 to 3.5 mm. Corning Glass #9092 mold material tends to exhibit about 50% greater mean deflection value at 3 mm than at 5 mm.

Because a negative lens is thin in the center and thick at the edge, more shrinkage tends to occur at the edge than at the center. Because a hemispherical section of glass will bend more readily toward its radius than away from it, in the case of a minus lens the front mold tends to accommodate the greater shrinkage at the edge by flexing and steepening. A positive lens is just the opposite. The thick section of a plus lens is its center and the edge is thin. The greater shrinkage of the center tends to cause the back (convex) mold to steepen and the front mold to flex very little. In this situation it is preferable to reduce the thickness of the back molds used to cast high diopter positive lenses so as to help reduce the polymerization strain.

The advantages of using a thinner mold are offset somewhat by two disadvantages. Using a thinner mold of the exact radius of curvature as a thicker mold will shift the final focusing power of the finished lens toward the plus side and therefore its radius must be compensated accordingly. Further, thicker molds tend to give better overall optics and show less distortion than the same lens cast with a thin mold.

Preferred mold thicknesses for lenses with a diameter of about 74 mm vary depending on the diopter of

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the lenses to be formed. For lenses in about the +2.0 to +4.0 diopter range, the front mold thickness is preferably about 2.5-7.0 mm, more preferably about 3.0-5.0 mm, and more preferably still about 3.5-4.0 mm, and the back mold thickness is preferably about 2.0-5.0 mm, more preferably 2.0-4.0 mm, and more preferably still about 2.5-3.0 mm. For lenses in about the zero ("plano") to +2.0 diopter range, the front mold thickness is preferably about 2.5-8.0 mm, more preferably about 3.5-6.0 mm, and more preferably still about 4.0-4.5 mm, and the back mold thickness is preferably about 2.0-8.0 mm, more preferably 3.0-6.0 mm, and more preferably still about 3.5-4.5 mm. For lenses in about the -2.0 to zero diopter range, the front mold thickness is preferably about 2.0-8.0 mm, more preferably about 3.0-6.0 mm, and more preferably still about 3.5-4.5 mm, and the back mold thickness is preferably about 2.5-8.0 mm, more preferably 3.5-6.0 mm, and more preferably still about 4.0-4.5 mm. For lenses in about the -4.0 to -2.0 diopter range, the front mold thickness is preferably about 2.0-6.5 mm, more preferably about 2.6-5.0 mm, and more preferably still about 3.2-4.0 mm, and the back mold thickness is preferably about 2.0-8.0 mm, more preferably 3.0-6.0 mm, and more preferably still about 4.0-4.5 mm. For lenses in about the -6.0 to -4.0 diopter range, the front mold thickness is preferably about 2.0-5.0 mm, more preferably about 2.0-4.0 mm, and more preferably still about 2.5-3.5 mm, and the back mold thickness is preferably about 2.0-8.0 mm, more preferably 3.0-6.0 mm, and more preferably still about 4.0-4.5 mm.

"Front" mold or face means the mold or face whose surface ultimately forms the surface of an eyeglass lens that is furthest from the eye of an eyeglass lens wearer. "Back" mold or face means the mold or face whose surface ultimately forms the surface of an eyeglass lens that is closest to the eye of a eyeglass lens wearer.

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To minimize premature release and produce water-white ophthalmic lenses, preferably a lens is initially cured as described above. That is, a lens forming material is preferably initially cured at relatively low temperatures, relatively low ultraviolet light intensity, and relatively low photoinitiator concentrations. "Initial" or "first" cure means the cure that transforms the liquid lens forming material into a solid material. Lenses produced as such generally have a Shore D hardness of about 60-78 (for the preferred compositions) when cured for about 15 minutes as described above. The hardness may be improved to about 80-81 Shore D by postcure heating the lens in a conventional oven for about 10 minutes, as described above. In the initial cure it is difficult to raise the hardness and surface cure of ultraviolet cured lenses above the levels described above. Achieving a higher degree of hardness and cure generally requires a faster, hotter reaction. The faster, hotter initial cure reaction, however, tends to lead to poorer yields and lessened lens optical quality.

In a preferred embodiment of the invention, factors such as the level of cure, rigidity, and hardness of ultraviolet light polymerized lenses may be improved. A method of the invention to improve these factors involves making a lens as described above, demolding the lens, and then subjecting the lens to relatively high intensity ultraviolet light postcure conditions. This method may be carried out using a system partially shown in Figure 9 including: (i) an apparatus 300 for making a plastic lens which includes (1) a first mold member, (2) a second mold member spaced apart from the first mold member, and the first and second mold members defining a mold cavity, (3) a first ultraviolet light generator for generating and directing ultraviolet light towards at least one of the first and second mold members during use, (4) an

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ultraviolet light filter disposed between the first ultraviolet light generator and the first mold member, and between the first ultraviolet light generator and the second mold member, and (5) a distributor for directing cooling fluid towards the first and second mold members during use; (ii) a second ultraviolet light generator 304 for generating and directing ultraviolet light towards the lens during use; and (iii) a first heater 306 to heat the lens during use. The system may also include a third ultraviolet light generator 308 for generating and directing ultraviolet light towards the lens during use after the lens has been heated. The system may also include a second heater 310 for heating the lens during use after the third ultraviolet light generator has directed light towards the lens. The system may also include a demolder 302, which may simply include a small hammer and chisel.

In a preferred embodiment the second and third ultraviolet light generators are the same generator. In a preferred embodiment the first and second heaters are the same heater. In a preferred embodiment the first and second heater may be incorporated with the second and third UV light generators. The system may also include additional heaters and or UV light generators.

Preferably the second and/or third ultraviolet light generators provide ultraviolet light at an intensity of about 150-300 mW/cm<sup>2</sup>, more preferably about 175-250 mW/cm<sup>2</sup>, at a wavelength range of about 360-370 nm (preferably about 365nm). Preferably the second and/or third ultraviolet light generators provide ultraviolet light at an intensity of about 50-150 Mw/cm<sup>2</sup>, more preferably about 75-125 mW/cm<sup>2</sup>, at a wavelength range of about 250-260 nm (preferably about 254 nm). The first or initial ultraviolet light generator preferably provides ultraviolet light at a total intensity (from both sides)

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of less than 10 mW/cm<sup>2</sup> (preferably about 0.3-2.0 mW/cm<sup>2</sup>). Thus preferably the second or third ultraviolet light generators provide at least about 2, 5, 10, 20, 40, 100, 500, 1000, and/or 1800 times the intensity of ultraviolet light than is provided by the first ultraviolet light generator. Preferably these generators provide about 40-100, 100-500, 500-1800, 100-1800, and/or 40-1800 times the amount of light provided by the first ultraviolet light generator. Preferably the lens is exposed to the ultraviolet light in the second, third and/or subsequent ultraviolet light generators for less than about 5 minutes, more preferably less than 1.0 minute, and more preferably still less than about 30 seconds. Preferably this exposure time is about 0.1-300 seconds, more preferably about 0.1-60 seconds, and more preferably still about 0.1-30 seconds. In another preferred embodiment the exposure time was less than 5 minutes. Generally as the intensity of the light is increased, the exposure time may be decreased, and vice versa.

Preferably the lens is heated in the first or second heaters for less than about 180 minutes, more preferably less than 30 minutes, and more preferably still less than about 10 minutes. Preferably the lens is heated in the second and/or third heaters at a temperature of about 65-180°C, more preferably about 85-140°C, and more preferably still about 100-120°C. Generally as the temperature is decreased, the amount of heating time should be increased, and vice versa. In another preferred embodiment the heating time was less than 5 seconds.

The lens is preferably cleaned (e.g., in a 50 volume % methanol/water solution) prior to exposing the lens to the relatively high intensity light. The relatively high intensity light may include relatively long and/or short wavelengths. The lens may then be heated. The lens may



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be repeatedly exposed to relatively high intensity ultraviolet light. The lens may be repeatedly heated.

In a preferred embodiment, the high intensity light  
5 may be provided with mercury vapor lamps provided in a  
UVEXS, Inc. Model CCU curing chamber (Sunnyvale, CA,  
U.S.A.).

It is believed that shorter wavelengths tend to  
10 improve the extent of surface cure and that longer  
wavelengths tend to increase the extent of cure within  
the middle portions of the lens. Thus it is preferably  
to use both shorter and longer ultraviolet light  
wavelengths for the second and third ultraviolet light  
15 generators. Exposure to the relatively high intensity UV  
wavelengths tends to yellow the lens, however  
subsequently heating the lens tends to reduce and/or  
eliminate this yellowing. Preferably the lens is heated  
to about 110-120°C. Heating also allows radicals to  
20 terminate and tends to increase the crosslinking of the  
compounds within the lens. The polymerization strain  
also tends to be reduced during heating.

Lenses cured according to the above procedure  
25 exhibited a Shore D hardness of above 83, with most lens  
about 83-85. These lenses also were more rigid and  
tended to warp less when inserted into an eyeglass frame  
after edging. There was negligible difference in the  
impact resistance and scratch resistance of the lenses  
30 cured in this fashion, compared to lenses cured without  
exposure to the relatively high intensity UV light. It  
is anticipated that the postcure methods described above  
will tend to remedy lesser defects that may occur in the  
first cure using the first UV light generator. For  
35 instance, the cure level for relatively low mass lenses  
during the first cure may be less important since the  
postcure will tend to ensure that the lenses are

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adequately cured. In like manner, different lens compositions that do not cure to form ophthalmic quality lenses in the first cure may be now usable since the postcure method may increase the quality of the cured  
5 lenses. For instance, the amount of photoinitiator and/or stabilizers in the initial composition may be varied over a broader range and still achieve acceptable water-white lenses.

10 In an alternate method for making a lens, the desired curvature (i.e., power) of the lens may be varied using the same molds, but with different light distributions. In this manner one mold may be used to prepare different lenses with different curvatures. The  
15 method includes the steps of: (1) placing a polymerizable lens forming material in a mold cavity defined in part between a first mold member and a second mold member, and wherein the cavity defines a theoretical curvature that is different from the desired curvature, (2) directing  
20 ultraviolet rays towards at least one of the first and second mold members, and wherein the ultraviolet rays are directed towards the first or second mold member such that the material cures to form a lens with the desired curvature, and (3) contacting fluid against the first or  
25 second mold member to cool the first or second mold member. The resulting lens curvature may vary depending on the way the ultraviolet light is directed towards the first or second mold members. That is, by varying the relative intensity of the light across the lens material  
30 radii, it is possible to vary the curvature of the resulting lens.

Lens curvatures may also vary when the lenses are subjected to postcure heating. Thus the curvature of the  
35 lenses may be varied by exposing the lens material to UV light, and then demolding and heating the lens. The heating may then result in the desired curvature, and

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this curvature may be different from the theoretical curvature expected from the dimensions of the mold cavity, as well as the curvature obtained after the lens has been exposed to the initial UV light.

5

The present invention will now be described in more detail with reference to the following examples. These examples are merely illustrative of the present invention and are not intended to be limiting.

10

**EXAMPLE 1 - LENS CURVATURE (POWER) VARIANCES**

Lenses were produced under various conditions according to the compositions, methods and apparatus of the present invention.

15

The formulation used to prepare the lenses according to this example included: 17.0% by weight of CR-73, 10.0% by weight of HDDMA, 21.0% by weight of TTEGDA, 32.0% by weight of TRPGDA, 20.0% by weight of TMPTA, 0.0356% by weight of methyl benzoylformate, 0.0095% by weight of Irgacure 184, and 0.16 ppm of Thermoplast Blue 684. The refractive index of this formulation ranged from 1.468 to 1.478. The refractive index of the lenses produced according to this example ranged from 1.507 to 1.511.

20

25

The method used to prepare the lenses according to this example was through the mold irradiation with air-cooling.

30

The gaskets used to prepare the lenses according to this example were GE SE6035 silicone rubber gaskets.

35

The molds used to prepare the lenses according to this example were made from Schott S-3 glass and had

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approximately parallel surfaces averaging 4 mm in thickness.

5       The intensity of ultraviolet light from the top measured at the center of the lens cell ranged from 0.35 mW/cm<sup>2</sup> to 0.37 mW/cm<sup>2</sup> for all lenses prepared according to this example. The ultraviolet lamps were kept at a temperature between 78 and 98 F.

10       For all lenses prepared according to this example, the upper light filter included 2 Pyrex glass sheets each frosted on one side with one sheet of tracing paper between them and the lower light filter also included 2  
15       Pyrex glass sheets each frosted on one side with one sheet of tracing paper between them. In some cases the lower light filter included an opaque disc. The opaque disk tended to decrease the amount of light reaching the mold members, with the decrease maximized at the center of the mold members. The light tended to decrease in  
20       lesser amounts at points more distant from the center.

The following curing conditions were constant for all lenses prepared according to this example:

25       -- ambient temperature -- 22°C  
      -- cooling air temperature -- 23.5°C  
      -- exit air flow rate  
          at vent 33 -- 20 ft<sup>3</sup>/min.  
      -- distance from disk to  
30       centerline of stage -- 38 mm.

The results are shown in Table 1 below. The results of this example for positive lenses demonstrate that as the diameter of the opaque disk at the lower light filter  
35       is increased: 1) the bottom light intensity is decreased, 2) the flexing of both the front and back molds is increased, 3) the power of the lenses before and

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after post-cure is reduced or less positive and, 4) the variance from the predicted power is reduced.

5       The results for negative lenses demonstrate that as  
the diameter of the opaque disk at the lower light filter  
is increased: 1) the bottom light intensity is  
decreased, 2) the flexing of both the front and back  
molds was essentially identical, 3) the power of the  
lenses before and after post-cure is increased or more  
10       negative, and, 4) the variance from the predicted power  
is reduced.

TABLE 1

Disc Diameter	Bottom Light Intensity In Center $m^w/cm^2$	Flexing Front Back mold mold	Power Upon Demolding	Power Upon Post-Cure	Predicted Power	Variance From Predicted Power
0	.51	-.05 -.09	+1.82	+1.92	+1.80	+1.12
21	.44	-.06 -.10	+1.76	+1.85	+1.80	+1.05
39	.33	-.09 -.13	+1.66	+1.75	+1.80	-.05
0	.51	+.10 +.04	-1.80	-1.91	-1.98	+.07
21	.44	+.09 +.04	-1.86	-1.94	-1.99	+.05
39	.33	+.07 +.02	-1.90	-1.97	-1.99	+.02
0	.51	+.18 +.06	-3.72	-3.94	-4.02	+.08
21	.44	+.18 +.07	-3.74	-3.96	-4.02	+.06
39	.33	+.14 +.05	-3.83	-4.00	-4.02	+.02

5

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The results shown in Table 1 clearly demonstrate that the lenses produced according to the present invention are in a stressed condition after ultraviolet light curing. The results also demonstrate that the stressed condition of the lenses may be reduced by an appropriate post-curing heating step. The results also demonstrate that the power of a finished lens produced according to the present invention may be altered by manipulating the intensity of ultraviolet light incident on a lens cell during the curing of a lens.

#### EXAMPLE 2 - LIQUID COOLING

As noted above, according to one embodiment of the present invention, the lens cell 52 may be cooled by disposing it in a liquid cooling bath. According to this process a lens was cured under the following conditions: The lens cell was made up of a 5.75 D front mold, a 7.50 D back mold and a silicone rubber gasket. The lens forming composition was 17% CR-73, 20% TMPTA, 21% TTEGDA, 32% TRPGDA, 10% HDDMA, .0336% MBZF, and .0084 Irgacure 184. The resultant center thickness was 2.4 mm. The lens molding cavity 82 was filled with lens forming material and the lens cell was placed on a supporting stage in a bath of 85% H<sub>2</sub>O with 15% propylene glycol at 0°C. A triangular array of ultraviolet lamps was utilized and the incident light intensity was 2.8 mW/cm<sup>2</sup> from the top and 1.5 mW/cm<sup>2</sup> from the bottom. The lens cell was irradiated for 10 minutes and the resultant lens had a measured focusing power of -1.80 D. The lens did not release and exhibited excellent stress patterns. The Shore D hardness was 67.

#### EXAMPLE 3 - THROUGH THE GASKET CURING

As noted above, according to one embodiment of the present invention, the lens forming material can be

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polymerized by irradiating only through the gasket. The lens forming composition was 26% CR-73, 25% HDDMA, 16% TMPTA, 15% TTEGDA, 16% TRPGDA, 2% styrene, .03% Irgacure 184, and about 0.3 ppm of Thermoplast Blue. According to this technique, a lens cell including a soft silicone rubber gasket configured for creating a -4.25 D lens was suspended in the center of a cylindrical array of Sylvania fluorescent F-15 8T/2052 lamps positioned at a distance from the lens cell to create an average light intensity of approximately 2 mw/cm<sup>2</sup> on the gasket 80 of the lens cell 52. The sample was irradiated for 40 minutes with 16 pounds of pressure being applied after 13 minutes of irradiation. The pressure was later increased to a total of 21.5 pounds. The lens did not release, gave excellent stress patterns and good optics.

#### EXAMPLE 4 - REDUCED TEMPERATURE CURING

Formulation:	17%	Bisphenol A BisAllyl Carbonate
	10%	1,6 Hexanediol dimethacrylate
	20%	Trimethylolpropane triacrylate
	21%	Tetraethyleneglycol diacrylate
	32%	Tripropyleneglycol diacrylate
	0.012%	1 Hydroxycyclohexyl phenyl ketone
	0.048	Methylbenzoylformate
	<10PPM	Hydroquinone & Methylethylhydroquinone

Hydroquinone and Methylethylhydroquinone were stabilizers present in some of the diacrylate and/or triacrylate compounds obtained from Sartomer. Preferably the amount of stabilizers is minimized since the stabilizers affect the rate and amount of curing. If larger amounts of stabilizers are added, then generally larger amounts of photoinitiators must also be added.

Light Condition:      mw/cm<sup>2</sup> measured at plane of sample



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	Center	Edge
	-----	-----
Top:	0.233	0.299
Bottom:	0.217	0.248

5

Air Flow: 9.6 standard cubic feet ("CFM") per manifold /  
19.2 CFM total on sample

Air Temperature: 4.4 degrees Centigrade

10

Molds: 80 mm diameter Corning #8092 glass

	Radius	Thickness
	-----	-----
Concave:	170.59	2.7
Convex:	62.17	5.4

15

Gasket: General Electric SE6035 silicone rubber with  
a 3 mm thick lateral lip dimension and a  
vertical lip dimension sufficient to provide  
an initial cavity center thickness of 2.2  
mm.

20

Filling: The molds were cleaned and assembled into  
the gasket. The mold/gasket assembly was  
then temporarily positioned on a fixture  
which held the two molds pressed against the  
gasket lip with about 1 kg. of pressure.  
The upper edge of the gasket was peeled back  
to allow about 27.4 grams of the monomer  
blend to be charged into the cavity. The  
upper edge of the gasket was then eased back  
into place and the excess monomer was  
vacuumed out with a small aspirating device.  
It is preferable to avoid having monomer  
drip onto the noncasting surface of the mold  
because a drop tends to cause the

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ultraviolet light to become locally focused and may cause an optical distortion in the final product.

5     Curing:       The sample was irradiated for fifteen  
minutes under the above conditions and  
removed from the curing chamber. The molds  
were separated from the cured lens by  
applying a sharp impact to the junction of  
10       the lens and the convex mold. The sample  
was then postcured at 110 °C in a  
conventional gravity type thermal oven for  
an additional ten minutes, removed and  
allowed to cool to room temperature.

15       Results:    The resulting lens measured 72 mm in  
diameter, with a central thickness of 2.0  
mm, and an edge thickness of 9.2 mm. The  
focusing power measured ~5.05 diopter. The  
20       lens was water clear ("water-white"), showed  
negligible haze, exhibited total visible  
light transmission of about 94%, and gave  
good overall optics. The Shore D hardness  
was about 80. The sample withstood the  
25       impact of a 1 inch steel ball dropped from  
fifty inches in accordance with ANSI 280.1-  
1987, 4.6.4 test procedures.

30       EXAMPLE 5 - REDUCED TEMPERATURE CURING

Formulation:	17%	Bisphenol A BisAllyl Carbonate
	10%	1,6 Hexanediol dimethacrylate
	20%	Trimethylolpropane triacrylate
35	21%	Tetraethyleneglycol diacrylate
	32%	Tripropyleneglycol diacrylate
	0.012%	1 Hydroxycyclohexyl phenyl ketone

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0.048% Methylbenzoylformate  
<10PPM Hydroquinone &  
Methylethylhydroquinone

5 Light Condition: mW/cm<sup>2</sup> measured at plane of sample

	Center	Edge
	-----	-----
Top:	0.251	0.330
10 Bottom:	0.236	0.265

Air Flow: 9.6 CFM per manifold / 19.2 CM total on sample

Air temperature: 4.4 degrees Centigrade

15

Molds: 80 mm dia. Corning #8092 glass

	Radius	Thickness
	-----	-----
20 Concave:	113.28	3.2
Convex:	78.64	5.5

Gasket: General Electric SE6035 silicone rubber with  
a 3 mm thick lateral lip dimension and a  
25 vertical lip dimension sufficient to provide  
a initial cavity center thickness of 1.9 mm.

Filling: The molds were cleaned and assembled into  
the gasket. The mold/gasket assembly was  
30 them temporarily positioned on fixture which  
held the two molds pressed against the  
gasket lip with about 1 kg. of pressure.  
The upper edge of the gasket was peeled back  
to allow about 15.1 grams of the monomer  
35 blend to be charged into the cavity. The  
upper edge of the gasket was then eased back  
into place and the excess monomer was

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vacuumed out with a small aspirating device. It is preferable to avoid having monomer drip onto the noncasting surface of the mold because a drop will cause the ultraviolet light to become locally focused too strongly on the monomer in the cavity and may cause an optical distortion in the final product.

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Curing: The sample was irradiated for fifteen minutes under the above conditions and removed from the curing chamber. The molds were separated from the cured lens by applying a sharp impact to the junction of the lens and the convex mold. the sample was then postcured at 110 degrees C in a conventional gravity type thermal oven for an additional ten minutes, removed and allowed to cool to room temperature.

Results: The resulting lens measured 73 mm in diameter, with a central thickness of 1.7 mm, and an edge thickness of 4.3 mm. The focusing power measured ~1.90 diopters. The lens was water clear, showed no haze, exhibited total visible light transmission of 94%, and gave good overall optics. The Shore D hardness was 81. The sample withstood the impact of a 7/8 inch steel ball dropped from fifty inches in accordance with ANSI Z80.1-1987, 4.6.4 test procedure.

#### EXAMPLE 6 - REDUCED TEMPERATURE CURING

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Formulation:	17%	Bisphenol A BisAllyl Carbonate
	10%	1,6 Hexanediol dimethacrylate
	20%	Trimethylolpropane triacrylate
	21%	Tetraethyleneglycol diacrylate

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32% Tripropyleneglycol diacrylate  
0.012% 1 Hydroxycyclohexyl phenyl ketone  
0.048% Methylbenzoylformate  
<10PPM Hydroquinone &  
methylethylhydroquinone

Light Condition: mW/cm<sup>2</sup> measured at plans of sample

	Center	Edge
Top:	0.233	0.299
Bottom:	0.217	0.248

Air Flow: 9.6 CFM per manifold / 19.2 CFM total on sample

Air Temperature: 12.3 degrees Centigrade

Molds: 80 mm dia. Corning #8092 glass

	Radius	Thickness
Concave:	170.59 mm	2.7 mm
Convex:	62.17 mm	5.4 mm

Gasket: General Electric SE6035 silicone rubber with a 3 mm thick lateral lip dimension and a vertical lip dimension sufficient to provide an initial cavity center thickness of 2.2 mm.

Filling: The molds were cleaned and assembled into the gasket. The mold/gasket assembly was then temporarily positioned on fixture which held the two molds pressed against the gasket lip with about 1 kg. of pressure. The upper edge of the gasket was peeled back to allow about 27.4 grams of the monomer

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blend to be charged into the cavity. The upper edge of the gasket was then eased back into place and the excess monomer was vacuumed out with a small aspirating device.

5 It is preferable to avoid having monomer drip onto the noncasting surface of the mold because a drop will cause the ultraviolet light to become locally focused too strongly on the monomer in the cavity and may cause

10 an optical distortion in the final product.

Curing: The sample was irradiated for fifteen minutes under the above conditions and removed from the curing chamber.

15 Results: The sample was found to have released from the front mold prematurely. The sample also showed signs of heat bubbling around the edges.

20

#### EXAMPLE 7 - REDUCED TEMPERATURE CURING

Formulation: 17% Bisphenol A BisAllyl Carbonate

10% 1,6 Hexanediol dimethacrylate

25 20% Trimethylolpropane triacrylate

21% Tetraethyleneglycol diacrylate

32% Tripropyleneglycol diacrylate

0.012% 1 Hydroxycyclohexyl phenyl ketone

0.048% Methylbenzoylformate

30 <10PPM Hydroquinone & Methylethylhydroquinone

Light Condition: mW/cm<sup>2</sup> measured at plane of sample

	Center	Edge
35	-----	-----
Top:	0.251	0.330
Bottom:	0.236	0.265

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Air Flow: 9.6 CFM per manifold / 19.2 CFM total on sample

Air Temperature: 12.3 degrees Centigrade

5    Molds:    80 mm dia.    Corning #8092 glass

	Radius	Thickness
	-----	-----
	Concave: 123.28 mm	3.2 mm
10	Convex: 78.64 mm	5.5 mm

Gasket:    General Electric SE6035 silicone rubber with  
a 3 mm thick lateral lip dimension and a  
vertical lip dimension sufficient to provide  
15    an initial cavity center thickness of 1.9  
mm.

Filling:    The molds were cleaned and assembled into  
the gasket. The mold/gasket assembly was  
20    then temporarily positioned on fixture which  
held the two molds pressed against the  
gasket lip with about 1 kg. of pressure.  
The upper edge of the gasket was peeled back  
to allow about 15.1 grams of the monomer  
25    blend to be charged into the cavity. The  
upper edge of the gasket was then eased back  
into place and the excess monomer was  
vacuumed out with a small aspirating device.  
It is preferable to avoid having monomer  
30    drip onto the noncasting surface of the mold  
because a drop will cause the ultraviolet  
light to become locally focused too strongly  
on the monomer in the cavity and may cause  
an optical distortion in the final product.

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Curing: The sample was irradiated for fifteen minutes under the above conditions and removed from the curing chamber. The molds were separated from the cured lens by applying a sharp impact to the junction of the lens and the convex mold. The sample was then postcured at 110 degrees C in a conventional gravity type thermal oven for an additional ten minutes, removed and allowed to cool to room temperature.

Results: The resulting lens measured 73 mm in diameter, with a central thickness of 1.7 mm, and an edge thickness of 4.3 mm. The focusing power measured -1.90 diopters. The lens was water clear, showed no haze, exhibited total visible light transmission of 94%, and gave good overall optics. The Shore D hardness was 81. The sample withstood the impact of a 7/8 inch steel ball dropped from fifty inches in accordance with ANSI 280.1-1987, 4.6.4 test procedure.

#### EXAMPLE 8 - REDUCED TEMPERATURE CURING

Formulation: 17% Bisphenol A BisAllyl Carbonate  
10% 1,6 Hexanediol dimethacrylate  
20% Trimethylolpropane triacrylate  
21% Tetraethyleneglycol diacrylate  
32% Tripropyleneglycol diacrylate  
0.009% 1 Hydroxycyclohexyl phenyl ketone  
0.036% Methylbenzoylformate  
<10PPM Hydroquinone &  
Methylethylhydroquinone

Light Condition: mW/cm<sup>2</sup> measured at plane of sample



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	Center	Edge
	-----	-----
Top:	0.233	0.299
Bottom:	0.217	0.248

5

Air Flow: 9.6 CFM per manifold / 19.2 CFM total on sample

Air Temperature: 12.2 degrees Centigrade

10 Molds: 80 mm dia. Corning #8092 glass

	Radius	Thickness
	-----	-----
Concave:	170.59 mm	2.7 mm
15 Convex:	62.17 mm	5.4 mm

20 Gasket: General Electric SE6035 silicone rubber with a 3 mm thick lateral lip dimension and a vertical lip dimension sufficient to provide an initial cavity center thickness of 2.2 mm.

25 Filling: The molds were cleaned and assembled into the gasket. The mold/gasket assembly was then temporarily positioned on fixture which held the two molds pressed against the gasket lip with about 1 kg. of pressure. The upper edge of the gasket was peeled back to allow about 27.4 grams of the monomer blend to be charged into the cavity. The upper edge of the gasket was then eased back into place and the excess monomer was vacuumed out with a small aspirating device. It is preferable to avoid having monomer drip onto the noncasting surface of the mold because a drop will cause the ultraviolet light to become locally focused too strongly

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on the monomer in the cavity and may cause an optical distortion in the final product.

- 5      Curing:      The sample was irradiated for fifteen minutes under the above conditions and removed from the curing chamber. The molds were separated from the cured lens by applying a sharp impact to the junction of the lens and the convex mold. The sample was then postcured at 110 degrees C in a conventional gravity type thermal oven for an additional ten minutes, removed and allowed to cool to room temperature.
- 10
- 15      Results:      The resulting lens measured 72 mm in diameter, with a central thickness of 2.0 mm, and an edge thickness of 9.2 mm. The focusing power measured -5.05 diopters. The lens was water clear, showed no haze, exhibited total visible light transmission of 94%, and gave good overall optics. The Shore D hardness was 80.5. The sample withstood the impact of a 1 inch steel ball dropped from fifty inches in accordance with ANSI 280.1-1987, 4.6.4 test procedure.
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- 25

#### EXAMPLE 9 - REDUCED TEMPERATURE CURING

Formulation:	17%	Bisphenol A BisAllyl Carbonate
30	10%	1,6 Hexanediol dimethacrylate
	20%	Trimethylolpropane triacrylate
	21%	Tetraethyleneglycol diacrylate
	32%	Tripropyleneglycol diacrylate
	0.012%	1 Hydroxycyclohexyl phenyl ketone
35	0.048%	Methylbenzoylformate
	<10PPM	Hydroquinone & Methyl ethylhydroquinone

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Light Condition:      mW/cm<sup>2</sup> measured at plane of sample

		Center	Edge
		-----	-----
5	Top:	0.251	0.330
	Bottom:	0.236	0.265

Air Flow: 9.6 CFM per manifold / 19.2 CFM total on sample

10 Air Temperature:      22.2 degrees Centigrade

Molds:      80 mm dia.    Corning #8092 glass

		Radius	Thickness
		-----	-----
15	Concave:	113.28 mm	3.2 mm
	Convex:	78.64 mm	5.5 mm

20 Gasket:      General Electric SE6035 silicone rubber with  
a 3 mm thick lateral lip dimension and a  
vertical lip dimension sufficient to provide  
an initial cavity center thickness of 1.9  
mm.

25 Filling:      The molds were cleaned and assembled into  
the gasket. The mold/gasket assembly was  
then temporarily positioned on fixture which  
held the two molds pressed against the  
gasket lip with about 1 kg. of pressure.  
The upper edge of the gasket was peeled back  
30 to allow about 15.1 grams of the monomer  
blend to be charged into the cavity. The  
upper edge of the gasket was then eased back  
into place and the excess monomer was  
vacuumed out with a small aspirating device.  
35 It is preferable to avoid having monomer  
drip onto the noncasting surface of the mold  
because a drop will cause the ultraviolet

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light to become locally focused too strongly on the monomer in the cavity and may cause an optical distortion in the final product.

5     Curing:     The sample was irradiated for fifteen minutes under the above conditions and removed from the curing chamber. The molds were separated from the cured lens by applying a sharp impact to the junction of  
10                   the lens and the convex mold. The sample was then postcured at 110 degrees C in a conventional gravity type thermal oven for an additional ten minutes, removed and allowed to cool to room temperature.

15               Results:     The resulting lens measured 73 mm in diameter, with a central thickness of 1.7 mm, and an edge thickness of 4.3 mm. The focusing power measured -1.87 diopters. The  
20                   lens was water clear, showed no haze, exhibited total visible light transmission of 94%, and gave good overall optics. The Shore D hardness was 83. The sample withstood the impact of a 1 inch steel ball  
25                   dropped from fifty inches in accordance with ANSI 280.1-1987, 4.6.4 test procedure.

**EXAMPLE 10 - REDUCED TEMPERATURE CURING**

30     Formulation: 17%        Bisphenol A BisAllyl Carbonate  
                  10%        1,6 Hexanediol dimethacrylate  
                  20%        Trimethylolpropane triacrylate  
                  21%        Tetraethyleneglycol diacrylate  
                  32%        Tripropyleneglycol diacrylate  
35                   0.009%   1 Hydroxycyclohexyl phenyl ketone  
                  0.036%   Methylbenzoylformate  
                  <10PPM   Hydroquinone &

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## Methylethylhydroquinone

Light Condition: Mw/cm<sup>2</sup> measured at plane of sample

5		Center	Edge
		-----	-----
	Top:	0.233	0.299
	Bottom:	0.217	0.248

10 Air Flow: 9.6 CFM per manifold / 19.2 CFM total on sample

Air Temperature: 22.2 degrees Centigrade

Molds: 80 mm dia. Corning #8092 glass

15

	Radius	Thickness
	-----	-----
Concave:	170.59 mm	2.7 mm
Convex:	62.17 mm	5.4 mm

20

Gasket: General Electric SE6035 silicone rubber with a 3 mm thick lateral lip dimension and a vertical lip dimension sufficient to provide an initial cavity center thickness of 2.2 mm.

25

Filling: The molds were cleaned and assembled into the gasket. The mold/gasket assembly was then temporarily positioned on fixture which held the two molds pressed against the gasket lip with about 1 kg. of pressure. The upper edge of the gasket was peeled back to allow about 27.4 grams of the monomer blend to be charged into the cavity. The upper edge of the gasket was then eased back into place and the excess monomer was vacuumed out with a small aspirating device.

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5 It is preferable to avoid having monomer  
drip onto the noncasting surface of the mold  
because a drop will cause the ultraviolet  
light to become locally focused too strongly  
on the monomer in the cavity and may cause  
an optical distortion in the final product.

10 Curing: The sample was irradiated for fifteen  
minutes under the above conditions and  
removed from the  
curing chamber.

15 Results: The sample was found to have released from  
the molds prematurely. It also showed heat  
bubbles at the edge.

**EXAMPLE 11 - HIGH INTENSITY UV POSTCURE - 1 COMPOSITION**

20 A number of lenses were prepared with the same  
physical molds and gasket, with the same lens forming  
composition, and under identical initial UV light curing  
conditions. These lenses were then subjected to various  
combinations of second and/or third UV intensity/time and  
temperature/time conditions. The results for Shore D  
25 hardness and impact resistance of each lens are shown in  
Table 2. The second or third UV source was a UVEXS CCU  
curing chamber configured with a medium pressure vapor  
lamp, a collimated dichroic reflector which reduced the  
IR radiation of the lamp by 50%, and two selectable  
30 output levels. The low setting provides approximately  
175 mW/cm<sup>2</sup> at about 365 nm and 70 mW/cm<sup>2</sup> at about 254 nm.  
The high setting produces about 250 mW/cm<sup>2</sup> at about 365 nm  
and 100 mW/cm<sup>2</sup> at about 254 nm. The initial curing  
conditions are identified below.

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Formulation:	17%	Biaphenol A BisAllyl Carbonate
	10%	1,6 Hexanediol dimethacrylate

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20% Trimethylolpropane triacrylate  
21% Tetraethyleneglycol diacrylate  
32% Tripropyleneglycol diacrylate  
0.012% 1 Hydroxycyclohexyl phenyl ketone  
0.048 Methylbenzoylformate  
<10PPM Hydroquinone &  
Methylethylhydroquinone

## Initial Cure

Light Condition: Mw/cm<sup>2</sup> measured at plane of sample

	Center	Edge
	-----	-----
Top:	0.251	0.330
Bottom:	0.236	0.265

Air Flow: 9.6 CFM per manifold / 19.2 CFM total on sample

Air Temperature: 4.8 degrees Centigrade

Molds: 80 mm dia. Corning #8092 glass

	Radius	Thickness
	-----	-----
Concave:	113.22	3.2
Convex:	78.52	5.2

Lens Power: -1.90 D  
Lens Thickness: 2.2 mm  
Lens Diameter: 73 mm

Gasket: General Electric SE6035 silicone rubber with  
a 3 mm thick lateral lip dimension and a  
vertical lip dimension sufficient to provide  
an initial cavity center thickness of 2.4  
mm.

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Curing: The sample was irradiated for fifteen minutes under the above conditions and removed from the curing chamber. The molds were separated from the cured lens by applying a sharp impact to the junction of the lens and the convex mold. The sample was then postcured as described. Unless otherwise indicated, the stated "hard" or high intensity UV postcure time/intensity doses were applied twice -- i.e., first to the convex surface and then to the concave surface for each exposure. For example, if the dose is described as "1.4 sec/low", it means that the front surface of the lens was exposed for 1.4 seconds to the low intensity rays and then the lens was turned over and the back was exposed for the same length of time to the same intensity level of light. The term "CX" means convex, the term "CC" means concave, the term "HD" means Shore D hardness, "pass" means the lens passed the 1" steel ball impact resistance test described in the previous examples (see e.g., example 9), "2nd UV" means the first UV postcure light (the initial cure was the "1st UV"), and "3rd UV" means the second UV postcure light. Time units are in minutes, unless "sec" for seconds is specified. Temperature is defined in degrees Centigrade.



TABLE 2  
HIGH INTENSITY UV/THERMAL POSTCURE EXAMPLES

#	2nd UV Lamp Time/Intensity	1st Thermal Postcure Time/Temp	3rd UV Lamp Time/Intensity	2nd Thermal Postcure Time/Temp	Shore D Hardness	Impact 1" Ball
1	0	0	0	0	65	--
2	0	10:00/115°C	0	0	80	Pass
3	1.4 sec/low	10:00/115°C	0	0	82	7/8"
4	0	5:00/115°C	1.4 sec/low	5:00/115C	83	Pass
5	1.4 sec/low	5:00/115°C	1.4 sec/low	5:00/115C	85	Pass
6	1.4 sec/low	5:00/ 65°C	1.4 sec/low	5:00/ 65C	80	Pass
7	1.4 sec/low	5:00/ 65°C	1.4 sec/low	15:00/65C	81	Pass
8	1.4 sec/low	5:00/ 65°C	1.4 sec/low	25:00/65 C	81	Pass
9	1.4 sec/low	5:00/ 80°C	1.4 sec/low	5:00/80C	82	Pass
10	1.4 sec/low	5:00/140°C	1.4 sec/low	5:00/140C	85	Pass
11	1.4 sec/low	5:00/180°C	1.4 sec/low	5:00/180C	85	Pass
12	12.0 sec/high	0	0	0	80	Pass
13	12.0 sec/high	1:00/180°C	0	0	83	Pass
14	12.0 sec/high	10:00/115°C	0	0	85	Pass
15	12.0 sec/high	30:00/ 65°C	0	0	83	Pass

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#	2nd UV Lamp Time/Intensity	1st Thermal Postcure Time/Temp	3rd UV Lamp Time/Intensity	2nd Thermal Postcure Time/Temp	Shore D Hardness	Impact 1" Ball
16	12.0 sec/high	10:00/115°C	1.0 sec/low	0	85	Pass
17	1.0 sec/low (Exposed CX side 1X only, CC side 0 times)	5:00/115°C	1.0 sec/low (Exposed CX side 1X only, CC side 0 times)	5:00/115C	83	Pass

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EXAMPLE 12 - HIGH INTENSITY UV POSTCURE -  
VARIOUS COMPOSITIONS

A number of lenses made from different compositions were prepared with the same physical molds and gasket, and under identical initial curing conditions. The lenses were then subjected to fixed postcure procedures with fixed UV intensity/time and temperature/time conditions. It should be noted that each of the acrylic components were passed through an alumina column to remove impurities and inhibitors before use. The results for Shore D hardness after the postcure, and the impact resistance of each product are shown in Table 3. The postcure UV source used was a UVEXS CCU curing chamber configured with a medium pressure vapor lamp, a collimated dichroic reflector which reduced the IR radiation of the lamp by 50%, and two selectable output levels. The low setting provides approximately 175 mW/cm<sup>2</sup> at about 365 nm and 70 mW/cm<sup>2</sup> at about 254 nm. The high setting produces about 250 mW/cm<sup>2</sup> at about 365 nm and 100 mW/cm<sup>2</sup> at about 254 nm. The initial curing conditions are identified below.

Initial Cure

Light Condition:      Mw/cm<sup>2</sup> measured at plane of sample

	Center	Edge
	-----	-----
Top:	0.233	0.299
Bottom:	0.217	0.248

Air Flow: 9.6 CFM per manifold / 19.2 CFM total on sample

Air Temperature:      4.8 degrees Centigrade

Molds:      80 mm dia. Corning #8092 glass

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	Radius	Thickness
	-----	-----
Concave:	113.22	3.2
Convex:	78.52	5.2

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Lens Power: -1.90 D  
Lens Thickness: 2.2 mm  
Lens Diameter: 73 mm

10 Gasket: General Electric SE6035 silicone rubber with a 3 mm thick lateral lip dimension and a vertical lip dimension sufficient to provide an initial cavity center thickness of 2.4 mm.

15

Curing: The sample was irradiated for fifteen minutes under the above conditions and removed from the curing chamber. The molds were separated from the cured lens by applying a sharp impact to the junction of the lens and the convex mold. The lens was then postcured by first exposing it to the low power setting in the UVEXS curing chamber (1.4 seconds each side after demolding). The sample was then placed in the thermal oven for five minutes at 115 degrees Centigrade, removed from the oven, and once again exposed for 1.4 seconds to the postcure UV at the low power setting. It was then returned to the thermal oven for another five minutes at 115 degrees Centigrade. The postcure UV doses were applied first to the convex surface and then to the concave surface for each exposure. For example, if the dose is described as "1.4 sec/low", it means that the front surface of the lens was exposed for 1.4

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seconds to the low intensity and then the lens was turned over and the back was exposed for the same length of time at the same intensity level. The impact resistance ("I/R") of each lens was pursuant to ANSI standards, as described for the other examples. The lenses were first tested with a 5/8" diameter steel ball bearing, a 7/8" steel ball bearing, and then a 1" steel ball bearing. The maximum diameter of ball bearing that the sample survived the impact of is described below. "CR-73" means bisphenol A bis(allyl carbonate), "MBZF" means methyl benzoylformate, "Irg. 184" means Irgacure 184.

TABLE 3

Composition	% MBZF	% Irg. 184	Total PI %	Shore D hardness after 1st UV	Final Shore D Hardness	I/R
CR-73 20% HDDMA 80%	0.086	0.265	0.351	57	85-86	1"
CR-73 20% TTEGDA 80%	0.0257	0.0064	0.0321	55	70	1"
CR-73 20% TRPGDA 80%	0.025	0.0062	0.031	48	75	1"
CR-73 20% TMPTA 80%	0.0461	0.0115	0.0576	50	87	5/8"
TMPTA 90% TRPGDA 10%	0.054	0.014	0.068	72	88	7/8"
TRPGDA 90% TMPTA 10%	0.0274	0.0068	0.0342	68-70	82	1"
TMPTA 36.5% HDDMA 24.4% TRPGDA 39.1%	0.096	0.048	0.144	68	87	1"
TMPTA 30% HDDMA 10% TRPGDA 60%	0.062	0.021	0.083	67	87	1"

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Composition	% MBZF	% Irg. 184	Total PI %	Shore D hardness after 1st UV	Final Shore D Hardness	I/R
TMPTA 30% CR-73 15% TTEGDA 22% TRPGDA 33%	0.0295	0.0074	0.0369	65	85	1"
HDDMA 100%	0.108	0.331	0.439	64-66	86-87	1"
HDDMA 94% CR-73 1.14% TMPTA 1.34% TTEGDA 1.41% TRPGDA 2.14%	0.12	0.16	0.28	50	86	1"
TTEGDA 100%	0.01	0.0025	0.0125	58-60	77	1"
TTEGDA 98.4% CR-73 0.3% HDDMA 0.2% TMPTA 0.4% TRPGDA 0.6%	0.059	0.015	0.074	70	78	1"
TRPGDA 100%	0.024	0.006	0.030	66	81-82	1"
CR-73 0.13% HDDMA 0.10% TMPTA 0.15% TTEGDA 0.16% TRPGDA 99.5%	0.0238	0.006	0.0244	67	82	1"
TMPTA 100%	0.058	0.014	0.072	56	89-91	1"

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Composition	% MBZF	% Irg. 184	Total PI %	Shore D hardness after 1st UV	Final Shore D Hardness	I/R
TTEGDA 0.38% CR-73 0.31% HDDMA 0.20% TMPTA 98.6% TRPGDA 0.58%	0.056	0.014	0.070	46	87	7/8"
HDDMA 100%	0.668	--	0.668	45	87	5/8"
HDDMA 100%	1.215	--	1.215	40	85	5/8"
TTEGDA 100%	0.018	--	.018	65	77	1"
TRPGDA 100%	0.0441	--	.0441	67	80	1"
TMPTA 100%	0.064	--	0.064	60	87	1"
TMPTA 100%	0.093	--	0.093	70	91	7/8"
CR-73 14.5% TRPGDA 85.5%	0.0377	--	0.0377	60	80	1"
CR-73 13.6% TMPTA 86.4%	0.074	--	0.074	52	85	1"
TMPTA 31.6% TTEGDA 37.2% TRPGDA 16.7% CR-73 14.5%	0.0205	--	0.0205	70	84	1"

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The initial UV curing time for each lens was 15 minutes, with the exception of the compositions with only TTEGDA with MBZF and Irgacure 184 (which had an initial curing time of 20 minutes), the compositions with only  
5 HDDMA and MBZF (which had an initial curing time of 45 minutes), the composition with only CR-73, TMPTA, and MBZF (which had an initial curing time of 20 minutes). The lenses that resulted were generally all water-white optically clear lenses with negligible yellowing and  
10 negligible haziness. The 100% TMPTA and 98.6% TMPTA lenses were slightly yellow but otherwise they were the same as the other lenses. These slightly yellow lens formulations may have the yellowness reduced with the addition of an effective amount of Thermoplast Blue added  
15 to the formulation.

Generally speaking, the single component (or primarily single component) lenses had generally less preferred optical qualities. Some of these lenses had  
20 slight wave patterns in some portions of the lenses.

It is thus seen that the methods, apparatus and compositions of the present invention provide several advantages. For example, according to certain  
25 embodiments of the present invention a plastic optical lens can be cured in 30 minutes or less. Furthermore, in certain embodiments of the present invention, the lens composition includes monomers having a higher refractive index than conventional monomer materials allowing the  
30 production of thinner lenses.

Although not specifically illustrated in the drawings, it is understood that other additional and necessary equipment and structural components will be  
35 provided, and that these and all of the components described above are arranged and supported in an

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appropriate fashion to form a complete and operative system.

It is also understood that variations may be made in the present invention without departing from the spirit and scope of the invention. Of course, other variations can be made by those skilled in the art without departing from the invention as defined by the appended claims.

#### FURTHER IMPROVEMENTS

##### Postcure With An Oxygen Barrier

In certain applications all of the lens forming composition may fail to completely cure by exposure to the first ultraviolet rays in the initial curing step. In particular, a portion of the lens forming composition proximate the gasket often remains in a liquid state following application of the first ultraviolet rays. It is believed that the gaskets are often somewhat permeable to air, and, as a result, oxygen permeates them and contacts the portions of the lens forming material that are proximate the gasket. Since oxygen tends to inhibit the photocuring process, portions of the lens forming composition proximate the gasket tend to remain uncured after application of the first ultraviolet rays.

Uncured lens forming composition proximate the gasket is a problem for several reasons. First, the liquid lens forming composition leaves the edges of the cured lens in a somewhat sticky state, which makes the lenses more difficult to handle. Second, the liquid lens forming composition is somewhat difficult to completely remove from the surface of the lens. Third, liquid lens forming composition may flow and at least partially coat the surface of lenses when such lenses are removed from the molds. This coating is difficult to remove and makes application of scratch resistant coatings or tinting dyes

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more difficult. This coating tends to interfere with the interaction of scratch resistant coatings and tinting dyes with the cured lens surface. Fourth, if droplets of liquid lens forming material form, these droplets may later cure and form a ridge or bump on the surface of the lens, especially if the lens undergoes later postcure or scratch resistant coating processes. As a result of the above problems, often lenses must be tediously cleaned or recast when liquid lens forming composition remains after the initial cure process.

The problems outlined above can be mitigated if less liquid lens forming composition remains proximate the gasket after the initial cure step. The following alternate embodiments of the invention have been developed to address this problem.

In one alternate embodiment of the invention, a plastic eyeglass lens may be made by the following steps:

- (1) placing a liquid polymerizable lens forming composition in a mold cavity defined by a gasket, a first mold member, and a second mold member;
- (2) directing first ultraviolet rays toward at least one of the mold members to cure the lens forming composition so that it forms a lens with a back face, edges, and a front face;
- (3) removing the gasket to expose the edges of the lens;
- (4) applying an oxygen barrier around the exposed edges of the lens; and
- (5) directing second ultraviolet rays towards the lens.

Steps 1-3 are substantially the same as described above (see, e.g., Figures 1-6, Examples 3-10, and related discussion). Steps 4-5 will be described in detail below.

A purpose of steps 4-5 is to reduce the amount of uncured liquid lens forming composition that is present when the lens is separated from the molds and/or gasket. It has been found that reducing the amount of liquid lens

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forming composition is especially advantageous if such reduction occurs before the molds are separated from the cured lens. This advantage results for the following reasons.

5

Separating the molds from the cured lens may cause uncured liquids to at least partially coat the lens faces. This coating occurs because uncured liquid lens forming composition tends to get swept over the faces  
10 when the molds are separated from the lens. It is believed that curing of the lens tends to create a vacuum between the lens and the mold. Air sweeps over the mold faces to fill this vacuum when the molds are separated from the lens. This air tends to take liquid lens  
15 forming composition into the vacuum with it.

In step 4 above, an oxygen barrier is applied to the edges or sides of the lens after the gasket is removed. Preferably the oxygen barrier is applied while the lens  
20 are still attached to the molds. In an alternate embodiment the oxygen barrier is also applied to the edges or sides of the molds at the same time it is applied to the sides of the lens. In a preferred embodiment, the sides of the lenses are first cleaned or  
25 wiped to remove at least a portion of the uncured liquid lens forming composition before the oxygen barrier is applied.

After the oxygen barrier is applied, second  
30 ultraviolet rays are directed towards the lens. After the second ultraviolet rays are directed toward the lens, at least a portion of the liquid lens forming composition which was not cured in the initial cure steps is cured. In this manner, the amount of liquid lens forming  
35 composition in contact with the cured lens is reduced. In a preferred embodiment, substantially all of the remaining liquid lens forming composition is cured after

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the second ultraviolet rays are directed toward the lens. More preferably, the lens is substantially dry after the second ultraviolet rays are directed towards the lens.

5       After the second ultraviolet rays are directed toward the lens, the lens may then be demolded. After the lens is demolded, a scratch resistant coating may be applied to the lens. In one embodiment, a scratch resistant coating is applied to the demolded lens by  
10       applying a liquid scratch resistant coating composition to a face of the lens and then applying ultraviolet rays to this face to cure the liquid scratch resistant coating to a solid.

15       In a preferred embodiment, the intensity of the ultraviolet rays applied to the face of the lens to cure the liquid scratch resistant coating composition to a solid is about 150-300 mW/cm<sup>2</sup> at a wave length range of about 360-370 nm, and about 50-150 mW/cm<sup>2</sup> at a wave length  
20       range of about 250-260 nm. In a preferred embodiment, the lens may be heated after removal from the molds, or after application of a scratch resistant coating to the lens.

25       In a preferred embodiment, the total intensity of the first ultraviolet rays directed toward the mold members is less than about 10 mW/cm<sup>2</sup>. Preferably the intensity of the second ultraviolet rays directed toward the lens is about 150-300 mW/cm<sup>2</sup> at a wave length range of  
30       about 360-370 nm, and about 50-150 mW/cm<sup>2</sup> at a wave length range of about 250-260 nm. Preferably the second ultraviolet rays are directed towards the lens for less than about 1 minute, as described above for the postcure process.

35       In a preferred embodiment, the above method may further comprise the additional step of directing third

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ultraviolet rays towards the lens before the oxygen barrier is applied. These third ultraviolet rays are preferably applied before the gasket is removed. Preferably, the second and third ultraviolet rays are  
5 directed toward the back face of the lens (as stated above, the second and third ultraviolet rays are preferably applied while this lens is in the mold cavity). The third ultraviolet rays are preferably about  
10 the same range of intensity as the second ultraviolet rays. The same apparatus may be used for both the second and third ultraviolet rays.

The same apparatus and processes described for the postcure processes may be used in the embodiments of the  
15 invention described in this "FURTHER IMPROVEMENTS" section. For instance, the same intensity and amount of second and third ultraviolet rays may be used both in these "FURTHER IMPROVEMENTS" processes and in the postcure process.

20 In a preferred embodiment, the method described above also includes the step of removing the oxygen barrier from the edges of the lens. The oxygen barrier is typically removed after the lens is cooled or allowed  
25 to cool.

In an alternate embodiment, the method described above may also include the step of heating the molds prior to application of the second ultraviolet rays, and  
30 more preferably prior to application of the oxygen barrier, and more preferably still prior to removal of the gasket. Heating the gasket and molds serves to transfer heat to the surface of the lens, which in turn tends to enhance the cure of any uncured liquid lens  
35 forming composition. It is to be understood that the amount of heat may vary, depending on the heating time and the quantity of second or third ultraviolet rays to

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be applied. As the heating time or quantity of ultraviolet light increases, then the heating temperature required may decrease. Preferably the molds and gasket are heated at a temperature of 90-170°C for 1-10 minutes, more preferably 120-150°C for 2-5 minutes.

The second and third ultraviolet rays may be repeatedly directed towards the lens. For instance, these ultraviolet rays may be applied via a light assembly whereby the lens passes under a light source on a movable stand. The lens may be repeatedly passed under the lights. Repeated exposure of the lens to the ultraviolet rays may be more beneficial than one prolonged exposure. In this manner the lens may have an opportunity to transfer heat from the lens (i.e. to cool the lens), or more evenly throughout various portions of the lens.

Preferably the oxygen barrier comprises a film, and more preferably a plastic, flexible, and/or elastic film. In addition, the oxygen barrier is preferably at least partially transparent to ultraviolet rays so that ultraviolet rays may penetrate the oxygen barrier to cure any remaining liquid lens forming composition. Preferably the oxygen barrier is stretchable and self-sealing. These features make the film easier to apply. Preferably the oxygen barrier is resistant to penetration by liquids, thus keeping any liquid lens forming composition in the mold assembly. Preferably, the oxygen barrier comprises a thermoplastic composition. It is anticipated that many different oxygen barriers may be used (e.g., saran wrap, polyethylene, etc.). In one preferred embodiment, the film is "Parafilm M Laboratory Film" which is available from American National Can (Greenwich, CT, U.S.A.). The oxygen barrier may also comprise aluminum foil.

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An apparatus for applying a scratch resistant coating composition to a lens and then curing the scratch resistant coating composition is described in U.S. patents 4,895,102 to Kachel et al. and 3,494,326 to Upton. In addition, the apparatus schematically shown in Figure 10 may also be used to apply the scratch resistant coating.

Figure 10 depicts an apparatus 600 with a first chamber 602 and a second chamber 604. This apparatus can be used to apply scratch resistant coating to a lens, to postcure a lens, or to apply ultraviolet light to a lens mold assembly. The first chamber 602 includes an opening 606 through which an operator can apply lenses and lens mold assemblies to the lens holder 608. Lens holder 608 is partially surrounded by barrier 614. First chamber 602 may include a light 610, and an opening 618 in the floor of the chamber.

Lens holder 608 is attached to device 612. It is envisioned that device 612 may be a spinning device which would permit the apparatus 600 to be used to apply scratch resistant coatings to lenses. In such case device 612 would connect directly to lens holder 608 through a hole in the bottom of barrier 614. In a preferred embodiment, however, device 612 just connects the lens holder 608 or barrier 614 to moving device 616. It has been found that a separate spinner (not shown) may provide better results for application of scratch resistant coatings to lenses.

Preferably barrier 614 has an interior surface that is made or lined with an absorbant material such as foam rubber. Preferably this absorbant material is disposable and removable. The absorbant material absorbs any liquids that fall off the lens holder 608, keeping in the interior surface of the barrier 614 clean.



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Second chamber 604 includes an opening 620 in its floor. It also includes an ultraviolet light assembly 622, which may include multiple lights and a light reflector.

5

The apparatus 600 includes an air filtering and distribution system. Air is pulled into a chamber 628 by fans 626 through a filter 624 (the quantity and locations of the fans and filters may vary). The filtered air is distributed by the fans 626 throughout chambers 602, 604, and 617. Air flows from point 613 to point 615 via air ducts (not shown) to reach chamber 617. The temperature of the lights and/or the second chamber may be controlled by turning various fans 629 on and off as needed to suck air out of chamber 604. Air is distributed from chamber 617 through holes 636 that are proximate the lower part of the opening 606 in the first chamber 602. Air is also sucked by fans 627 from the first chamber 602 to chamber 630 through holes 634 that are proximate the top part of the opening 606 in the first chamber 602. This arrangement tends to prevent contaminants from entering first chamber 606. Air is discharged from chamber 630 to the surroundings via fans 627.

During use a lens or lens mold assembly may be placed on the lens holder 608. A button can be pressed, causing the moving device 616 to move device 612, lens holder 604, and the barrier 614 so that they are under the opening 620 in the second chamber 604. Light is thus applied to the lens or lens mold assembly from light assembly 622. After a set period of time, the moving device 616 moves everything back to a location underneath the opening 618 in the first chamber 602.

The lens holder 608 may include a suction cup connected to a metal bar. The concave surface of the suction cup may be attachable to a face of a mold or

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lens, and the convex surface of the suction cup may be attached to a metal bar. The metal bar may be attachable to a lens spinner.

5       The lens holder may also alternately include movable arms and a spring assembly which are together operable to hold a lens against the lens holder with spring tension during use. A drawing of this embodiment of the lens holder is shown in Figures 11 and 12. Figure 11 depicts  
10       a top view of a lens holder 700, which includes a substantially flat surface 702 and movable arms 704 held together with a spring 706. The surface 702 also includes raised lips 708 which are substantially traverse raised lips 710 on the movable arms.

15       As shown in Figure 12, raised lips 708 and 710 protrude above the plane of the flat surface 702. Raised lips 708 and 710 serve to hold a lens in place when this lens is placed on substantially flat surface 702. Figure  
20       11 depicts the lens holder in a relaxed position without a lens attached to it. In operation, ends 712 of the movable arms 704 may be brought closer together by swiveling about a substantially centralized point 716, thereby moving ends 714 of arms 704 further apart. When  
25       ends 714 are moved further apart, additional space is provided on the surface 702 for placement of a lens or a mold. Moving ends 714 further apart also has the effect of increasing spring tension in the spring 706.

30       After the lens is placed on the surface 702, the arms 704 may be allowed to relax. Spring tension in the spring 706 causes the ends 714 to move closer together and ends 712 to move further apart. Ends 714 then contact edges of the lens or mold assembly placed on the  
35       surface 702. More specifically the edges of this lens or mold assembly contacts raised lips 708 and 710. Spring tension in spring 706 helps to keep raised lips 708 and

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710 in contact with the edges of the lens or mold assembly, thus holding the lens or mold assembly in place. Once the lens or mold assembly is held in place, the lens holder may be spun by rotating shaft 718 in a lens spinner.

Preferably the lens holder is at least partially made of aluminum, Delrin, or other hard but light materials. If made of aluminum, the surface of the lens holder must be treated to inhibit light reflection. In a preferred embodiment, raised lips 708 and 710 protrude an amount of less than about 720 above the plane of substantially flat surface 702. Preferably, amount 720 is less than about 5.0 mm, more preferably less than about 3.0 mm, and more preferably still about 1.0 to 3.0 mm. In one embodiment amount 720 was 0.06 inches (about 1.52 mm). Amount 720 must be large enough to contact enough of the edges to hold the lens in place, but must not so large that materials that are spin coated on the surface of a lens placed on the lens holder may run off the edges of the lens and accumulate proximate the raised lips 708 or 710, or splash back onto the lens. Thus a careful balancing must be accomplished to optimize amount 720.

25

Preferably raised lips 708 are about one inch apart when the diameter of the substantially flat surface 702 is about 2.9 inches.

30

#### OXYGEN BARRIER EXAMPLE #1

A liquid lens forming composition was initially cured as in a process and apparatus similar to that specified in Example 11. The composition was substantially the same as specified in Example 11, with the exception that hydroquinone was absent, the concentration of methylethylhydroquinone was about 40-50

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ppm, the concentration of 1 hydroxycyclohexyl phenyl ketone was 0.017 percent, and the concentration of methylbenzoylformate was 0.068 percent. The composition underwent the initial 15 minute cure under the "1st UV."

5 The apparatus was substantially the same as described for Example 11, with the following exceptions:

1. The air flowrate on each side of the lens mold assembly was estimated to be about 18-20 CFM.

10

2. The apparatus was modified in that air flowed to and from the openings 96 and orifices 98 (which were themselves substantially unchanged) through a duct behind the lens forming chamber, instead of through pipes (e.g. pipe 12 in Figure 5). Essentially plenum portion 95 was expanded so that the walls of the chamber are the walls of the plenum portion 95. Figure 14 depicts a front view of this lens curing apparatus 800. Air in apparatus 800 flows from the orifices 98, over the lens mold assembly 802, through ducts 804, through fan 806, through heat exchanger 808, and then through ducts 810 and back to orifices 98 via air return conduits 824 (shown on Figure 15).

15

20

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Figure 14 also shows a water chiller 812 which cools water and then sends it through conduits 814 and through heat exchanger 808. Figure 14 also shows lights 816 and frosted glass 818.

30

The chamber 820 surrounding lights 816 is not connected to the chamber 822 around the mold assembly 802. In this manner chilled air from orifices 98 does not contact and cool the lights 816 (such cooling tends to cause excessive changes in light output). The chamber 820 is cooled by fans (not shown) which turn on and off depending on the temperature of

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the surface of the lights 816. Figure 15 shows a side view of apparatus 800.

- 5           3.   The air flowrate in and out of the chamber  
              surrounding the lights was varied in accordance  
              with the surface temperature of lights. The  
              air flowrate was varied in an effort to keep  
              the temperature on the surface of one of the  
10           lights between 104.5°F and 105°F.
4.   The ultraviolet light output was controlled by  
              varying the power sent to the lights as the  
              output of the lights varied (see discussion  
15           below).
5.   Frosted glass was placed between the lights and  
              the filters used to vary the intensity of the  
              ultraviolet light across the face of the molds.  
              Preferably the glass was frosted on both sides.  
20           The frosted glass acts as a diffuser between  
              the lights and these filters. This frosted  
              glass tended to yield better results if it was  
              placed at least about 2 mm from the filter,  
              more preferably about 10-15 mm, more preferably  
25           still about 12 mm, from the filter. Frosted  
              glass was found to dampen the effect of the  
              filters. For instance, the presence of the  
              frosted glass reduced the systems' ability to  
              produce different lens powers by varying the  
30           light (see Example 1 and Figure 1).
6.   In Figure 3 the center lights 40 are shown in a  
              triangular arrangement when viewed from the  
              side. These lights were rearranged to provide  
35           an in-line arrangement.

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After initial cure, the lens mold assembly was removed from the curing chamber. The lens mold assembly included a lens surrounded by a front mold, a back mold, and a gasket between the front and back molds (see, e.g., the assembly in Figure 6).

At this point the protocol in Example 11 stated that the lens was demolded (see above). While demolding at this point is possible, as stated above generally some liquid lens forming composition remained, especially in areas of the lens proximate the gasket. Therefore the lens was not demolded as stated in Example 11. Instead, the gasket was removed, liquid lens forming composition was wiped off the edges of the lens, and a layer of oxygen barrier (Parafilm M) was wrapped around the edges of the lens while the lens was still between the molds. The Parafilm M was wrapped tightly around the edges of the lens and then stretched so that it would adhere to the lens and molds (i.e. in a manner similar to that of Saran wrap). The lens mold assembly was then placed in apparatus 600 so that the back face of the lens (while between the molds) could then be exposed to second ultraviolet light.

This second ultraviolet light was at a substantially higher intensity than the initial cure light, which was directed at an intensity of less than 10 mW/cm<sup>2</sup>. The second ultraviolet light corresponded to the high light setting in Example 11. The mold assembly was passed in and out of second chamber 604 in Figure 10 when the light was set at the high setting. Passing in and out of the chamber took about 22 seconds. The total light energy applied during these 22 seconds was about 4500 millijoules per square centimeter ("mJ/cm<sup>2</sup>").

Preferably the total light energy applied per pass under the second and third ultraviolet ray lights was in

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the range of about 500-10,000 mJ/cm<sup>2</sup>, more preferably about 3000-6000 mJ/cm<sup>2</sup>, and more preferably still 4000-5000 mJ/cm<sup>2</sup>. Light energy may be varied by varying the time of exposure, or the intensity of the light. Light energy was measured with a Model IL390B Light Bug from International Light, Inc. (Newburyport, MA, U.S.A.). The total light energy represents the total amount of ultraviolet light over the range of 250 to 400 nm.

It has been found that applying ultraviolet light at this point helped to cure some or all of the remaining liquid lens forming composition. The second ultraviolet light step may be repeated. In this example the second ultraviolet light step was repeated once. It is also possible to expose the front or both sides of the lens to the second ultraviolet light.

After the second ultraviolet light was applied, the mold assembly was allowed to cool. The reactions caused by exposure to ultraviolet light are exothermic. More importantly, the ultraviolet lights tend to emit infrared light which in turn heats the mold assembly. The lens was then demolded. The demolded lens was substantially drier and harder than lenses that are directly removed from mold assemblies after the initial cure step.

#### OXYGEN BARRIER EXAMPLE #2

The protocol of Oxygen Barrier Example #1 was repeated except that prior to removal of the gasket the lens mold assembly was positioned so that the back face of the lens was exposed to third ultraviolet light. In this case the third ultraviolet light was at the same intensity and for the same time period as one pass of the second ultraviolet light. It has been found that applying third ultraviolet light at this point helped to

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cure some or all of the remaining liquid lens forming composition so that when the gasket was removed less liquid lens forming composition was present. All of the remaining steps in Oxygen Barrier Example #1 were applied, and the resultant lens was substantially dry when removed from the molds.

Postcure With A Second Composition Curable With Oxygen Present

10

In an alternate embodiment of the invention, the lens may be processed as described above except that the oxygen barrier is omitted. Instead, steps 1-3 are repeated, excess liquid lens forming composition is removed, and then a second composition is applied to at least a portion of the exposed sides of the lens. This second composition is preferably bondable to the lens and substantially curable by exposure to ultraviolet light in the presence of oxygen. After the second composition is applied, the second ultraviolet rays are then directed towards the lens.

In this embodiment of the invention the second composition is preferably applied by holding the gasket-free mold assembly such that the faces of the molds and lens are vertically aligned. The second composition may be applied by dispensing droplets of second composition on the top of the uppermost portions of the sides of the lens. Gravity and surface forces force the second composition to flow around on the sides of the lens. Preferably less than 5.0 milliliters ("ml") is applied, and more preferably 4-5 drops are applied.

A second composition is preferably selected that will bond with the lens and the liquid lens forming composition during application of the second ultraviolet rays to form a substantially dry surface on the lens. In



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a preferred embodiment the second composition was substantially the same as the first composition except that the second composition had at least about five times the amount of photoinitiator present, more preferably at least about 10 times the amount of photoinitiator present, and more preferably still at least about 20 times the amount of photoinitiator present. In a preferred embodiment the second composition was the same lens forming composition as described in Example 11, except that it had 2.5 % of Irgacure 184 photoinitiator present (the MBZF in the photoinitiator was replaced with Irgacure 184 since Irgacure 184 is more reactive than MBZF). Preferably the photoinitiator in the second composition is more reactive than the photoinitiator in the lens forming composition.

In general the second composition is preferably curable in the presence of oxygen. It should also be compatible with the lens and liquid lens forming composition. It is possible to make some lens forming compositions curable in the presence of oxygen by adding large portions of photoinitiator to them, and/or by replacing the photoinitiator in them with a more reactive photoinitiator. Such second compositions are generally not usable as lens forming compositions because they tend to cure unevenly and prematurely release from molds during cure. Nevertheless, such compositions may be used as second compositions since they are used in small quantities to form relatively thin layers.

In an alternate embodiment of the invention the mold assembly may be processed without an oxygen barrier by applying the ultraviolet light in an oxygen free environment. For instance, after initial cure the mold assembly may be removed, and then placed in a light transparent compartment or box. The compartment may then be purged of oxygen with a substantially oxygen-free gas

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stream (e.g., a substantially inert gas such as nitrogen, argon, helium, or a mixture thereof). The compartment may then be exposed to ultraviolet light to cure any remaining liquid lens forming composition. Alternately, the gasket may be removed from the mold assembly prior to placing the mold assembly in the compartment. In another alternate embodiment the mold assembly may be placed in a light chamber which included a substantially oxygen-free environment.

#### Postcure While In The Mold Assembly

In an alternate embodiment of the invention, the lens may be formed by the following steps: (1) placing a liquid polymerizable lens forming composition in a mold cavity defined by at least a gasket, a first mold member, and a second mold member, (2) directing first ultraviolet rays at a total intensity of less than about 10 mW/cm<sup>2</sup> toward at least one of the mold members to cure the lens forming composition so that it forms a lens with a back face, sides, and a front face, (3) directing second ultraviolet rays at an intensity of about 150-300 mW/cm<sup>2</sup> at a wavelength range of about 360-370 nm, and about 50-150 mW/cm<sup>2</sup> at a wavelength range of about 250-260 nm towards the lens while the lens is still in the mold cavity, and (4) demolding the lens. This method of the invention serves to reduce or eliminate any excess liquid lens forming composition remaining after the first cure without having to remove the gasket while liquid lens forming composition remains. It is believed to be advantageous if the gasket is made as transparent and oxygen impermeable as possible without losing other characteristics that make the gasket adaptable for the initial curing steps. Semitransparent gaskets that are substantially oxygen impermeable may be adequate for this application.

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Ultraviolet Light Control

It has been found that consistent results are more difficult if light output varies during a single application, or between different applications. Varying light outputs tend to cause lens production to decrease because of increased occurrence of premature release, etc. In this respect lens curing applications differ from many other applications where ultraviolet light is applied (e.g., coatings, etc.). In other applications, the light output is normally not carefully controlled. Acceptable results are achievable as long as the light output is within a certain range. With lens casting applications, however, the lens forming material is much thicker and the final product quality must be much higher. As a result, the process is much more sensitive to variables such as light output, temperature, etc.

Light outputs vary depending on the age of the lights, the manufacturer of the lights, voltage variances, etc. For instance, it was discovered that light outputs could vary significantly from one location to another location. As a result, a lens casting apparatus that worked well in one location would not necessarily work well in another location. Even apparatus in the same location would vary widely in performance due to voltage variances over the course of a day, the age of the lights, etc.

To control light output, attempts were made to add equipment to control electric voltages within narrow ranges. This equipment was relatively expensive and did not solve the problem of output variances due to quality differences, light age, etc. These other output variances can be controlled by testing the lights upon receipt and by replacing the lights after a certain amount of use, however such steps are somewhat expensive

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and require excessive amounts of accounting to track individual lights.

The light output problem was ultimately solved by measuring and controlling the light itself by varying the amount of power applied to the lights in response to changes in light output. Specifically, a preferred embodiment of the invention includes a light sensor mounted near the lights. This light sensor measures the amount of light, and then a controller increases the power supplied to maintain the first ultraviolet rays as the intensity of the first ultraviolet rays decreases during use, and vice versa. Specifically, the power is varied by varying the voltage supplied to the lights. In a preferred embodiment the light sensor is applied as close as possible to the cell holder 70 in Figure 2.

The preferred "lamp driver" or light controller was a Mercron Model FX0696-4 and Model FX06120-6 (Mercron -- Dallas, Texas, U.S.A.). These light controllers may be described in U.S. patents 4,717,863 and 4,937,470.

Figure 13 schematically depicts the light control system described above. The lights 40 in apparatus 10 apply light towards the lens holder 70. A light sensor 700 is located adjacent the lights 40. Preferably the light sensor 700 is a photoresistor light sensor (photodiodes or other light sensors may also be usable in this application). The light sensor 700 is connected to lamp driver 702 via wires 704. Lamp driver 702 sends a current through the light sensor 700 and receives a return signal from the light sensor 700. The return signal is compared against an adjustable set point, and then the amount of voltage sent to the ultraviolet lights 40 via wires 706 is varied depending on the differences between the set point and the signal received from the

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light sensor 700. Preferably the light output is maintained within about +/- 1.0 percent.

#### Other Lens Forming Compositions

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One possible problem with the lens forming and scratch resistant coating compositions of the invention is that some lens making personnel are allergic to these compositions when they are in the liquid uncured form.

10 To solve this problem, substitute compounds were found as replacements for the ingredients of these compositions. Many of the substitute compounds were ethoxylated.

One lens forming composition, dubbed "PRO-629" or  
15 "OMB-91," was composed of the following components:

	<u>Component</u>	<u>%</u>
	Irgacure 184 (Ciba-Geigy)	0.017
20	Methylbenzoyl formate (Aldrich)	0.068
	TMPTA (SR-351)	20.0
	TTEGDA (SR-268)	21.0
	TPGDA (SR-306)	32.0
	HDDMA (SR-239)	10.0
25	CR-73 (PPG)	17.0
	Thermoplast blue p (BASF)	0.35 ppm
	4-methoxyphenol (inhibitor)	≤ 45 ppm

The term "SR" means Sartomer Company. For instance,  
30 "SR-351" is a name designated by Sartomer for the Sartomer brand of TMPTA. The inhibitor was present in the compounds obtained from Sartomer. The lens composition described above was found to form lenses with desirable properties at the following condition:

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1. Light Intensity (measured at 365 nm) was ≤ 0.3 mW/cm<sup>2</sup> per face of mold.

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2. Cooling air temperature was about 4-10°C.
3. The casting period was 15 min. with maximum temperature of the composition occurring after 10 min.
4. After initial cure, the lens was passed under the "high" setting of ultraviolet light described in Example 11 (1 pass for the front face and 2 passes for the back face).
5. The formed lenses had a hardness of about 83 (Shore D).

The choice of ingredients for the lens forming and scratch resistant compositions is limited by its safety (i.e., toxicity, odor, skin irritation, etc.). Pro-629 components are generally low in toxicity and considered relatively safe and stable, although gloves and goggles are recommended when handling these compositions. Nevertheless, further improvements are possible with additional changes to the composition. The following PRO-629 composition was modified as follows:

	<u>Pro-629</u>	<u>Modified Composition</u>
In	0.085%	0.06%
TMPTA	20.0%	20.5% (SR-454)
TTEGDA	21.0%	21.5% (SR-344)
TRPGDA	32.0%	32.8%
HDDMA	10.0%	10.2%
CR-73	17.0%	15.0%
TPb	0.35 PPM	0.25

The term "In" means the amount of initiator present. The initiator used was a mixture of 20 percent Irgacure 184 and 80 percent methylbenzoyl formate. The term "TPb"

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means thermoplast blue. All of the above compounds were passed through an alumina column to remove impurities (including the inhibitor). The resulting composition was substantially odorless.

5

The modified composition had an index of refraction at 20°C of 1.471 versus an index of refraction of 1.4735 for the PRO-629 composition.

10       Maximum temperatures in the lens forming composition during curing took place after about 580 seconds for the PRO-629 composition and after about 490 seconds for the modified composition. Resulting lenses were water-clear and exhibited good optical qualities. The lenses  
15       produced with the PRO-629 composition had a hardness of about 83 Shore D, and the lenses produced with the modified composition had a hardness of about 77-78 Shore D.

20       The modified formula of PRO-629 was made by replacing SR-351 with SR-454 and SR-268 with SR-344. The concentration of photoinitiator was reduced in the modified composition so that the time when the maximum temperature was achieved was approximately the same as  
25       for the PRO-629 composition. The modified composition exhibited the following results when cured to form an eyeglass lens:

- 30       1.   Reaction speed was comparable to PRO-629  
          (@ cooling air temp. of 4-5°C).
2.   Lens power was comparable to PRO-629.
- 35       3.   Shore D hardness was a maximum of 78,  
          which is less than the PRO-629 Shore D  
          hardness of 83-85.

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4. Impact resistant was slightly better than PRO-629 (at a center thickness of about 1.4 mm).
5. The final color after heat treatment was water clear, which was slightly better the final color of PRO-629 lenses.

The reduction in hardness is related to the absence of TMPTA, and to a lower concentration of photoinitiator. Ethoxylated TMPTA produces a softer lens, which in turn causes the lens to have improved impact resistant and clarity. This composition may be preferred in thicker lenses when the hardness difference is less important.

15

#### Scratch Resistant Coatings

A scratch resistant coating composition used for the back face of the lens included:

20

- |           |                                                      |
|-----------|------------------------------------------------------|
| 3.23 %    | Irgacure 184,                                        |
| 0.75 %    | Darocur 1173 (from Ciba-Geigy),                      |
| 0.75 %    | Irgacure 500,                                        |
| 15.05 %   | Tripropylene glycol diacrylate (SR-306),             |
| 25 5.51 % | Polyethylene glycol (400) diacrylate (SR-344),       |
| 15.33 %   | Ethoxylated trimethylolpropane triacrylate (SR-454), |
| 2.06 %    | Urethane acrylate (CN 964E75) (from Sartomer),       |
| 30 ppm    | flow agent (HC-900) (from Coburn),                   |
| 30 17.4 % | ethanol,                                             |
| 14.9 %    | acetone, and                                         |
| 25 %      | isopropyl alcohol.                                   |

This coating achieved about 10-15 psi of scratch resistance using the 3M steel wool test. As the scratch resistance was improved, it was discovered that impact resistance decreases. Thus the amount of decreased

35



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impact resistance was a limiting factor on coatings for the lens. In addition, the composition used for the back face of the mold formed a surface that was easier to tint than the surface formed with the front face composition.

5

A scratch resistant coating composition used for the front face of the lens included:

- |    |          |                                                     |
|----|----------|-----------------------------------------------------|
|    | 2.75 %   | Irgacure 184,                                       |
| 10 | 0.67 %   | Darocur 1173 (from Ciba-Geigy),                     |
|    | 0.67 %   | Irgacure 500                                        |
|    | 13.0 %   | Tripropylene glycol diacrylate (SR-306)             |
|    | 4.5 %    | Polyethylene glycol (400) diacrylate (SR-344)       |
|    | 14.75 %  | Pentaerythritol triacrylate (SR-444)                |
| 15 | 13.1 %   | Ethoxylated trimethylolpropane triacrylate (SR-454) |
|    | 1.75 %   | Urethane acrylate (CN 964E75) (from Sartomer)       |
|    | 28.4 ppm | flow agent (HC-900) (from Coburn),                  |
|    | 14.7 %   | ethanol,                                            |
| 20 | 12.6 %   | acetone, and                                        |
|    | 21.5 %   | isopropyl alcohol.                                  |

This coating achieved about 40 psi of scratch resistance using the 3M steel wool test.

25

The scratch resistant coating compositions described above may be used for "in-mold" scratch resistant coating applications. An in-mold scratch resistant coating process is described in U.S. patents 4,758,448 and 4,544,572. The in-mold scratch coating process of the invention included the following steps:

coating a face of a first mold member with a liquid polymerizable scratch resistant coating material comprising an least two ethylenically unsaturated groups;

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directing ultraviolet rays toward the first mold member to cure the scratch resistant material such that greater than 70 percent of the ethylenically unsaturated groups are reacted;

5

forming a mold cavity defined in part by the first mold member, and a second mold member;

10

filling the mold cavity with a polymerizable lens forming material;

15

directing first ultraviolet rays toward at least one of the mold members to cure the lens forming material so that it forms an eyeglass lens coated with the scratch resistant coating material.

20

The first ultraviolet rays correspond to the first ultraviolet rays described above which are used to form the lens. The ultraviolet rays used to partially cure the coating composition to react at least about 70 % (more preferably at least about 80 %, more preferably still at least about 90%) of the ethylenically unsaturated groups was at the same intensity as the "low" setting described above for the postcure in Example 11.

25

The total amount of light to partially cure the coating composition was preferably about 600 millijoules per square cm ("mJ/cm<sup>2</sup>"), although it is anticipated that 50-1000 mJ/cm<sup>2</sup> would also operate adequately.

30

Scratch resistance of the scratch resistant coating may be increased by increasing the amount of postcure exposure time and/or intensity applied to that coating. Too much exposure time and/or intensity may detrimentally affect impact resistance of the lens.

35

It is possible to measure the percent of reaction of the ethylenically unsaturated groups with a Fourier

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Transform Infra-red Spectrometer ("FTIR"). One such FTIR is the Galaxy Series FTIR 3000 made by Mattson (Madison, Wisconsin, U.S.A.). Preferably a relatively high percentage of the ethylenically unsaturated groups are reacted by the second ultraviolet rays described above. In general, the higher the percentage of reaction, the more dry and stable the coating composition is when the lens forming composition is applied. It is important for the coating to be as dry and stable as possible. Otherwise, the coating may deform when the lens forming composition is applied, when the molds are handled, or when the mold cavity is formed. Such coating deformity tends to create optical distortions in the finished lens, making such lens unusable.

Although a high percentage of reaction is desired for the coating composition, if the percent of reaction is too high after the initial ultraviolet rays are applied, then the coating will not adequately adhere to the lens forming composition. This problem was recognized in the art (e.g. U.S. patents 4,758,448 and 4,544,572). As a result, persons skilled in the art generally only initially cured the coating composition such that less than about 70 % of the ethylenically unsaturated groups reacted. See U.S. patents 4,758,448 and 4,544,572.

The above described in-mold process may further comprise the steps of applying a postcure (e.g., see Example 11) or applying a postcure with an oxygen barrier, applying a postcure with second composition that is curable in the presence of oxygen, or applying a postcure while the lens is in the mold assembly (see previous discussion). It is believed that the postcure steps enhance the cure of the scratch resistant coating compositions and/or the lens forming compositions. In addition, it is believed that the postcure steps enhance

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the bond between the coating composition and the lens forming composition. As a result, coated lenses may be produced wherein the coating exhibits an adhesion to the lens forming composition of at least 90% when tested according to ASTM D-3359. The coatings on these lenses exhibit such adhesion despite the fact that over 70%, 80%, or even 90% of the ethylenically unsaturated groups in the coating are reacted prior to application of the lens forming material.

10

Thus the process of the invention allows a more complete cure of the scratch resistant coating composition prior to application of the lens forming composition. As a result, the partially cured coating composition may be made so that it is substantially drier and more stable, thus reducing the chance for deformity during when the lens forming composition is applied, the molds handled, etc. In addition, the presence of a flow agent (e.g., HC-900) allows a greater degree of cure in the coating composition since this flow agent tends to act as a mold release agent. Thus the formed lens will still release from the glass molds even after enhanced cure of the coating composition.

25

In one experiment the effect of exposure to ultraviolet light on the curing on in-mold lens coating was studied to determine the amount of residual double bond remaining after partial cure of the coating. Several coating compositions were spin coated on a sodium chloride plate. The sodium chloride plate acted as an I-R window. FTIR spectra of these compositions was then recorded. The plate was then exposed to second ultraviolet light under a "low" light intensity setting of the lights described in Example 11. The area under the bands in the 1640-1620  $\text{cm}^{-1}$  regions were measured as an indication of double bond. The uncured composition was used as a "100%" reading and the amount of residual

30

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double bond was calculated using the area of the cured sample. Results were as follows:

	<u>Sample</u>	<u>Exposure (mJ/cm<sup>2</sup>)</u>	<u>% Double Bond Remaining</u>
5			
	Back Coat 1	35	32
	Back Coat 2	47	22
	Back Coat 3	64	15
	Back Coat 4	88	9
10	Back Coat 5	112	9
	Back Coat 6	198	6
	Front Coat 1	197	20
	Front Coat 2	413	15
	Front Coat 3	620	10

15

The results shown above were obtained using spin coating to produce films that were substantially similar to the thin coatings on lenses. Differing results caused by differences in coating thickness were mitigated by measuring before and after ultraviolet light exposure.

20

It is also possible to apply scratch resistant coating to lenses after they are demolded. These "out-of-the-mold" processes are well known, and primarily involve coating a lens face with scratch resistant coating composition, and then curing the coating composition by thermal or photocuring processes.

25

A first preferred scratch resistant coating composition which may be used for out-of-the-mold processes includes the following:

30

1.57 % Irgacure 184,  
1.6 % propoxylated neopentyl glycol diacrylate (SR-9003),  
12.8 % dipentaerythritol pentaacrylate (SR-399),  
0.032 % flow agent (FC-430),

35

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33.6 % 1-methoxypropanol,  
29.4 % acetone, and  
21 % isopropyl alcohol.

5 As with the other compositions disclosed in this application, all composition percentages are by weight unless otherwise stated. FC-430 is available from 3M Company, Minneapolis, MN, U.S.A.

10 A second such preferred scratch resistant coating composition includes:

1.98 % Irgacure 184,  
22.2 % dipentaerythritol pentaacrylate (SR-399),  
15 0.047 % surfactant (DC-193),  
48.3 % 1-methoxypropanol,  
27.5 % ethanol.

The DC-193 was available from Dow Corning Company.  
20 The second scratch resistant coating composition had a higher flash point than the first scratch resistant coating composition. A higher flash point is preferred, especially if the compositions will be applied in a retail environment.

25 Both the in-mold and the out-of-the-mold coating compositions described above can be used for both in-mold and out-of-the-mold processes, however scratch resistance is enhanced if they are used as directed above.

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CLAIMS

1. A method for making a plastic eyeglass lens,  
comprising the steps of:

5

placing a liquid polymerizable lens forming  
composition in a mold cavity defined by at  
least a gasket, a first mold member, and a  
second mold member;

10

directing first ultraviolet rays toward at least one  
of the mold members to cure the lens forming  
composition so that it forms a lens with a back  
face, edges, and a front face;

15

removing the gasket to expose the edges of the lens;

applying an oxygen barrier around the exposed edges  
of the lens; and

20

directing second ultraviolet rays towards the lens.

2. The method of claim 1 wherein the lens forming  
composition is cured to form the lens in less than one  
hour.

25

3. The method of claim 1 wherein the lens forming  
composition is cured to form the lens in less than thirty  
minutes.

30

4. The method of claim 1 wherein a portion of the  
liquid lens forming composition proximate to the gasket  
remains a liquid after the first ultraviolet rays are  
directed towards at least one of the mold members.

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5. The method of claim 4, further comprising the step of removing at least part of the remaining liquid lens-forming composition from the lens after the gasket is removed but before the second ultraviolet rays are directed towards the lens.
6. The method of claim 4 wherein at least a portion of the remaining liquid lens forming composition is cured after the second ultraviolet rays are directed towards the lens.
7. The method of claim 1 wherein the lens is substantially dry after the second ultraviolet rays are directed towards the lens.
8. The method of claim 1, further comprising the additional step of directing third ultraviolet rays towards the lens before the oxygen barrier is applied.
9. The method of claim 1, further comprising the additional step of directing third ultraviolet rays towards the lens before the gasket is removed.
10. The method of claim 8 wherein the third ultraviolet rays are directed towards the back face of the lens.
11. The method of claim 1 wherein the second ultraviolet rays are directed towards the back face of the lens.



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12. The method of claim 1, further comprising the step of removing the oxygen barrier from the sides of the lens.
- 5 13. The method of claim 12 wherein the lens is cooled or allowed to cool before the oxygen barrier is removed.
- 10 14. The method of claim 1 wherein the oxygen barrier comprises a flexible film.
- 15 15. The method of claim 1 wherein the oxygen barrier is at least partially transparent to ultraviolet rays.
- 20 16. The method of claim 1 wherein the oxygen barrier is stretchable.
- 25 17. The method of claim 1 wherein the oxygen barrier is self-sealing.
- 30 18. The method of claim 1 wherein the oxygen barrier is resistant to penetration by liquids.
- 35 19. The method of claim 1 wherein the oxygen barrier comprises a thermoplastic composition.
20. The method of claim 1, further comprising the step of demolding the lens after the second ultraviolet rays are directed toward the lens.

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21. The method of claim 20, further comprising the steps of applying a liquid scratch resistant coating composition to the front face of the lens and then applying ultraviolet rays to the front face of the lens to cure the liquid scratch resistant coating composition to a solid.

22. The method of claim 21 wherein the intensity of the ultraviolet rays applied to the front face of the lens to cure the liquid scratch resistant coating composition to a solid is about 150-300 mW/cm<sup>2</sup> at a wavelength range of about 360-370 nm, and about 50-150 mW/cm<sup>2</sup> at a wavelength range of about 250-260 nm.

23. The method of claim 1, further comprising the additional step of heating the lens after the second ultraviolet rays are directed towards the lens.

24. The method of claim 1 wherein the total intensity of the first ultraviolet rays directed toward the mold members is less than about 10 mW/cm<sup>2</sup>.

25. The method of claim 1 wherein the intensity of the second ultraviolet rays directed toward the lens is about 150-300 mW/cm<sup>2</sup> at a wavelength range of about 360-370 nm, and about 50-150 mW/cm<sup>2</sup> at a wavelength range of about 250-260 nm.

26. The method of claim 1 wherein the second ultraviolet rays are directed toward the lens for less than about 1 minute.

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27. The method of claim 8 wherein the intensity of the third ultraviolet rays directed toward the lens is about 150-300 mW/cm<sup>2</sup> at a wavelength range of about 360-370 nm, and about 50-150 mW/cm<sup>2</sup> at a wavelength range of about 250-260 nm.

28. The method of claim 8 wherein the third ultraviolet rays are directed toward the lens for less than about 1 minute.

29. The method of claim 1, further comprising the step of controlling the intensity of the first ultraviolet rays by varying power supplied to the first ultraviolet rays as the intensity of the first ultraviolet rays varies during use.

30. The method of claim 1, further comprising the step of controlling the intensity of the first ultraviolet rays by increasing power supplied to the first ultraviolet rays as the intensity of the first ultraviolet rays decreases during use, and vice versa.

31. The method of claim 1, further comprising the step of controlling the intensity of the first ultraviolet rays by increasing voltage supplied to the first ultraviolet rays as the intensity of the first ultraviolet rays decreases during use, and vice versa.

32. The method of claim 1, further comprising the step of controlling the intensity of the second ultraviolet rays by varying power supplied to the second ultraviolet rays as the intensity of the second ultraviolet rays varies during use.

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33. The method of claim 1, further comprising the step of controlling the intensity of the third ultraviolet rays by varying power supplied to the third ultraviolet rays as the intensity of the third ultraviolet rays varies during use.

34. The method of claim 1 wherein second ultraviolet rays are repeatedly directed towards the lens.

35. The method of claim 8 wherein third ultraviolet rays are repeatedly directed towards the lens.

36. The method of claim 1, further comprising the step of heating the mold assembly prior to removing the gasket.

37. The method of claim 8, further comprising the step of heating the mold assembly prior to applying the third ultraviolet rays.

38. The method of claim 36 wherein the mold assembly is heated at a temperature of about 90-170°C.

39. The method of claim 37 wherein the mold assembly is heated at a temperature of about 90-170°C.

40. A method for making a plastic eyeglass lens, comprising the steps of:

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placing a liquid polymerizable lens forming composition in a mold cavity defined by at least a gasket, a first mold member, and a second mold member;

5

directing first ultraviolet rays toward at least one of the mold members to cure the lens forming composition so that it forms a lens with a back face, edges, and a front face;

10

removing the gasket to expose the edges of the lens;

applying a second composition to at least a portion of the exposed edges of the lens, the second composition being bondable to the lens and substantially curable by exposure to ultraviolet light in the presence of oxygen; and

15

directing second ultraviolet rays towards the lens.

20

41. The method of claim 40 wherein a portion of the liquid lens forming composition proximate to the gasket remains a liquid after the first ultraviolet rays are directed towards at least one of the mold members.

25

42. The method of claim 41, further comprising the step of removing at least part of the remaining liquid lens-forming composition from the lens after the gasket is removed but before the second ultraviolet rays are directed towards the lens.

30

35

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43. The method of claim 41 wherein the lens is substantially dry after the second ultraviolet rays are directed towards the lens.

5

44. The method of claim 41 wherein the second composition bonds with the lens and the liquid lens forming composition during application of the second ultraviolet rays to form a substantially dry surface on the lens.

10

45. The method of claim 40 wherein less than about 5.0 ml of the second composition are applied to the lens.

15

46. The method of claim 40 wherein the second composition is substantially the same as the first composition except that the second composition has at least about five times the amount of photoinitiator present.

20

47. The method of claim 40 wherein the second composition comprises at least about five times the amount of photoinitiator as the lens forming composition.

25

48. The method of claim 40, further comprising the additional step of directing third ultraviolet rays towards the lens before the second composition is applied.

30

49. The method of claim 40, further comprising the additional step of directing third ultraviolet rays towards the lens before the gasket is removed.

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50. A method for making a plastic eyeglass lens, comprising the steps of:

- 5       placing a liquid polymerizable lens forming composition in a mold cavity defined by at least a gasket, a first mold member, and a second mold member;
- 10       directing first ultraviolet rays at a first intensity toward at least one of the mold members to cure the lens forming composition so that it forms a lens with a back face, sides, and a front face;
- 15       directing second ultraviolet rays at an second intensity of at least about 10 times the intensity of the first ultraviolet rays towards the lens while the lens is still in the mold cavity;
- 20       demolding the lens.

25       51. The method of claim 50 wherein the first intensity totals less than about 10 mW/cm<sup>2</sup> and the second intensity is about 150-300 mW/cm<sup>2</sup> at a wavelength range of about 360-370 nm, and about 50-150 mW/cm<sup>2</sup> at a wavelength range of about 250-260 nm.

30

52. The method of claim 50 wherein the first ultraviolet rays are directed for a time period of less than one hour.

35

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53. The method of claim 50 wherein the second ultraviolet rays are directed for a time period of less than one minute.

5

54. The method of claim 50 wherein a portion of the liquid lens forming composition proximate to the gasket remains a liquid after the first ultraviolet rays are directed towards at least one of the mold members.

10

55. The method of claim 54 wherein at least a portion of the remaining liquid lens forming composition is cured after the second ultraviolet rays are directed towards the lens.

15

56. The method of claim 50, further comprising the step of removing the gasket before the second ultraviolet rays are directed towards the lens.

20

57. The method of claim 50 wherein the second ultraviolet rays are applied in an environment comprising less oxygen than air.

25

58. The method of claim 56 wherein the second ultraviolet rays are applied in an environment comprising less oxygen than air.

30

59. The method of claim 57 wherein the environment comprises nitrogen.

35



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60. The method of claim 58 wherein the environment comprises nitrogen.

5 61. A method for making a plastic eyeglass lens, comprising the steps of:

10 placing a liquid polymerizable lens forming material in a mold cavity defined by a gasket, a first mold member, and a second mold member;

15 directing ultraviolet rays toward at least one of the mold members to cure the lens forming material so that it forms a solid lens with a back face, edges, and a front face; and

20 controlling the intensity of the ultraviolet rays by varying power supplied to provide the ultraviolet light during use.

25 62. The method of claim 61 wherein the power is varied by varying the voltage during use.

30 63. The method of claim 61 wherein the power is varied by increasing the power as the intensity of the ultraviolet rays decreases during use, and vice versa.

35 64. The method of claim 61 wherein the power is varied by increasing voltage as the intensity of the ultraviolet rays decreases during use, and vice versa.

65. An apparatus for making a plastic eyeglass lens, comprising:

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a first mold member;

a second mold member spaced apart from the first  
mold member, and the first and second mold  
members defining a mold cavity during use;

an ultraviolet light generator for generating and  
directing ultraviolet light toward at least one  
of the first and second mold members during  
use;

a sensor to measure ultraviolet light intensity  
during use; and

a controller connected to the light sensor and which  
varies power to the ultraviolet light generator  
during use as the intensity of the ultraviolet  
light varies during use.

66. The apparatus of claim 65 wherein the controller  
compares the ultraviolet light intensity to a set value  
during use.

67. The apparatus of claim 65 wherein the controller  
varies voltage to the ultraviolet light generator during  
use as the intensity of the ultraviolet light varies  
during use.

68. The apparatus of claim 65 wherein the controller  
increases power as the light intensity decreases during  
use, and vice versa.

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69. The apparatus of claim 65 wherein the controller increases voltage as the light intensity decreases during use, and vice versa.

5

70. A method of preparing a plastic eyeglass lens with a scratch resistant coating, comprising:

10 coating a face of a first mold member with a liquid polymerizable scratch resistant coating composition comprising ethylenically unsaturated groups;

15 directing ultraviolet rays toward the first mold member to partially cure the scratch resistant composition such that greater than 70 percent of the ethylenically unsaturated groups are reacted;

20 forming a mold cavity defined in part by the coated face of the first mold member, and a second mold member;

25 filling the mold cavity with a polymerizable lens forming composition;

30 directing first ultraviolet rays toward at least one of the mold members to cure the lens forming composition so that it forms an eyeglass lens coated with the scratch resistant coating material.

35 71. The method of claim 70 wherein at least about 80 percent of the ethylenically unsaturated groups in the scratch resistant coating composition react when the ultraviolet rays are directed to the first mold member.

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72. The method of claim 70 wherein at least about 90 percent of the ethylenically unsaturated groups in the scratch resistant coating composition react when the  
5 ultraviolet rays are directed to the first mold member.

73. The method of claim 70 wherein the scratch resistant coating composition comprises at least two ethylenically  
10 unsaturated groups.

74. The method of claim 70 wherein the ethylenically unsaturated groups comprise acrylyl or methacrylyl  
15 groups.

75. The method of claim 70 wherein the coating composition exhibits an adhesion to the lens forming  
20 composition of at least 90% when tested according to ASTM D-3359.

76. The method of claim 70 wherein the lens forming  
25 composition and the scratch resistant composition both comprise at least two ethylenically unsaturated groups selected from the group of acrylyl and methacrylyl.

30 77. The method of claim 70, further comprising the step of applying a second ultraviolet rays to the lens.

78. The method of claim 70, further comprising the step  
35 of applying a third ultraviolet rays to the lens.

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79. The method of claim 70 wherein the total intensity of the first ultraviolet rays directed toward the mold members is less than about 10 mW/cm<sup>2</sup>.

5

80. The method of claim 77 wherein the intensity of the second ultraviolet rays directed toward the lens is about 150-300 mW/cm<sup>2</sup> at a wavelength range of about 360-370 nm, and about 50-150 mW/cm<sup>2</sup> at a wavelength range of about 250-260 nm.

10

81. The method of claim 77 wherein the second ultraviolet rays are directed toward the lens for less than about 1 minute.

15

82. The method of claim 79 wherein the intensity of the third ultraviolet rays directed toward the lens is about 150-300 mW/cm<sup>2</sup> at a wavelength range of about 360-370 nm, and about 50-150 mW/cm<sup>2</sup> at a wavelength range of about 250-260 nm.

20

83. The method of claim 79 wherein the third ultraviolet rays are directed toward the lens for less than about 1 minute.

25

84. The method of claim 70 wherein about 50-1000 mJ/cm<sup>2</sup> of light are applied to partially react the coating composition.

30

85. The method of claim 64 wherein the coating composition comprises a release agent.

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86. A lens made by the method of any one of claims 1, 5, 6, 7, 8, 14, 15, 29, 37, 40, 50, 61 or 70.

1 / 10

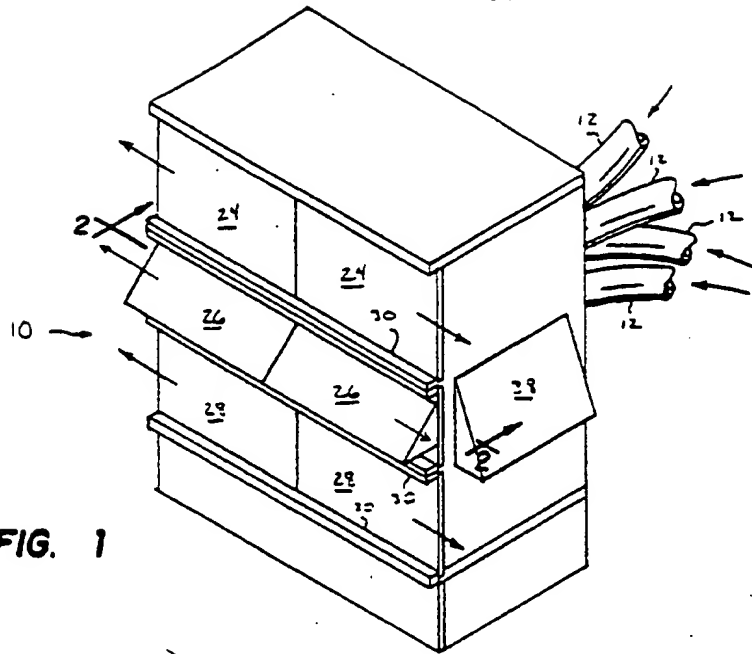


FIG. 1

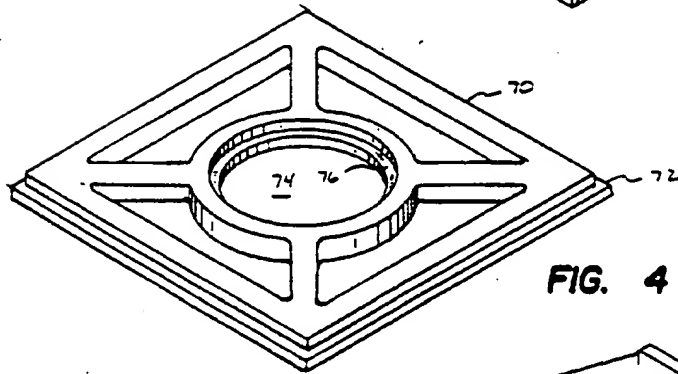


FIG. 4

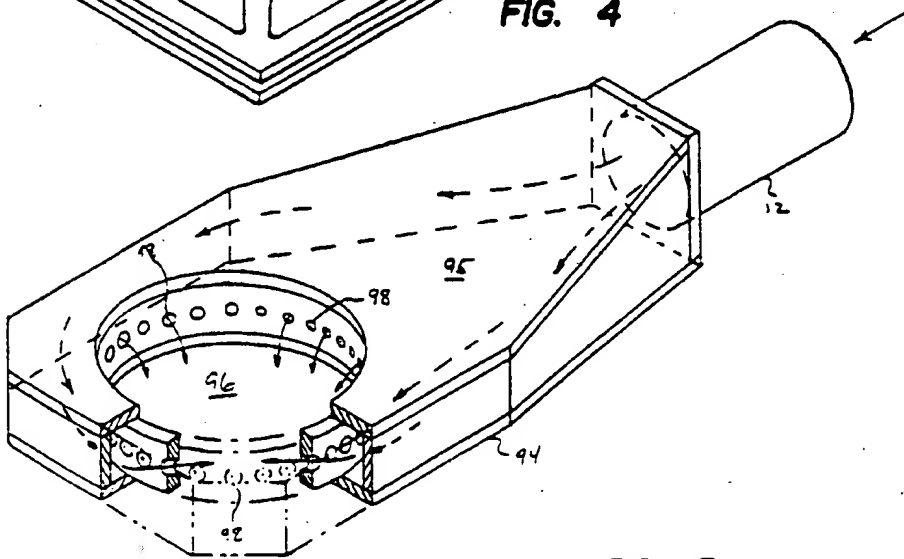
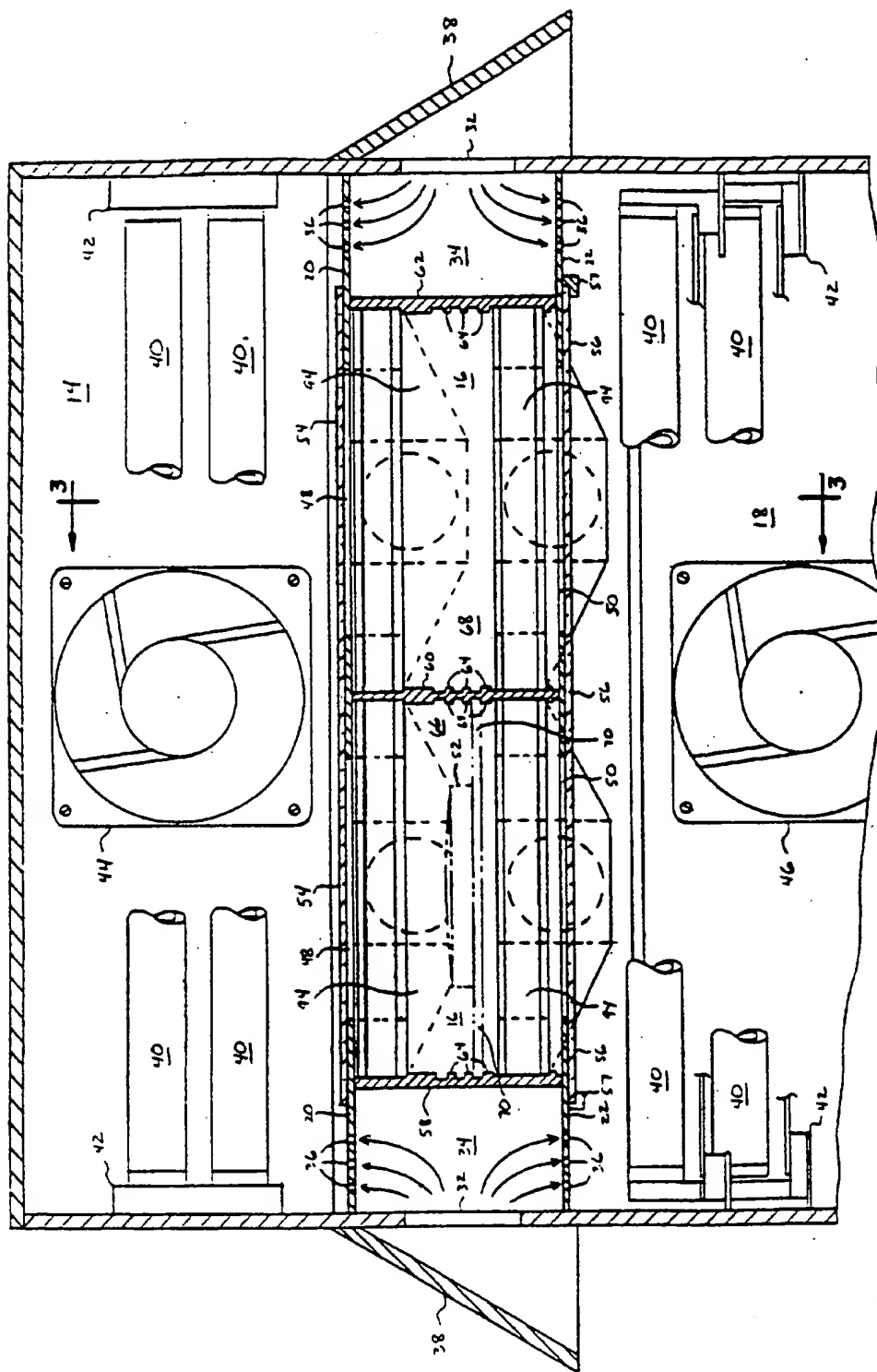


FIG. 5



**FIG. 2**



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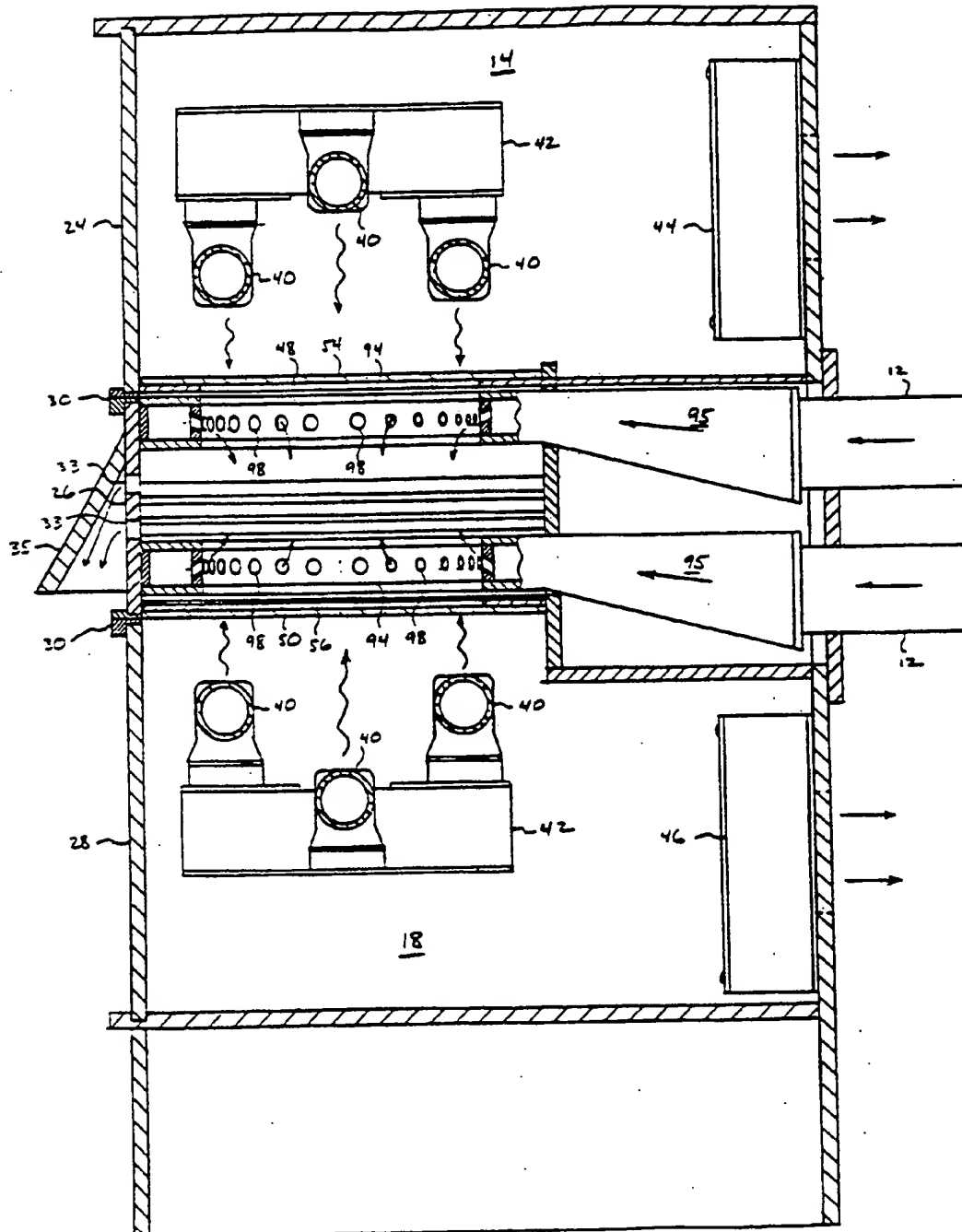


FIG. 3

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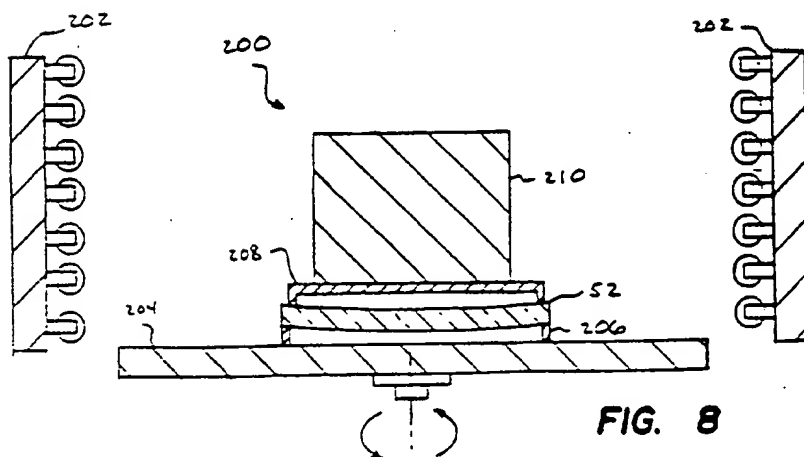
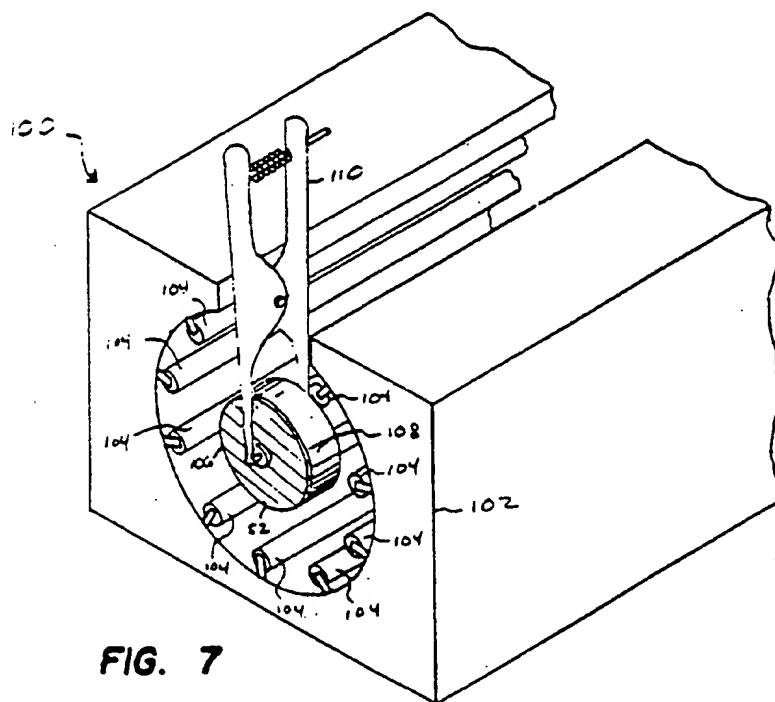
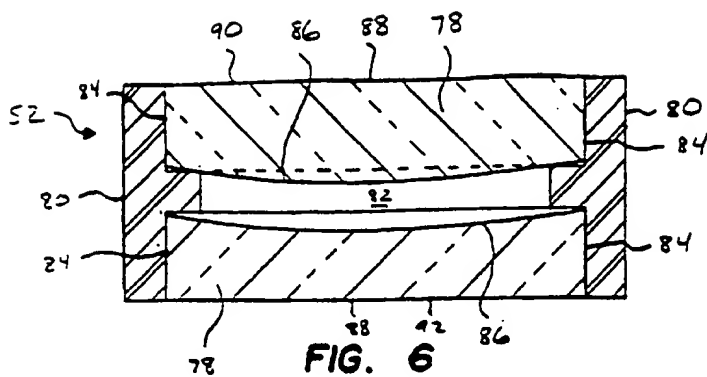
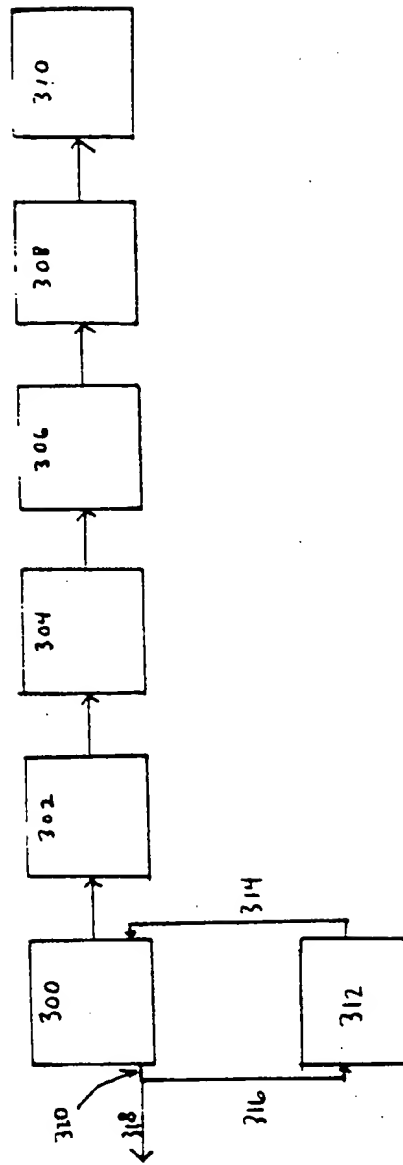


FIG. 9



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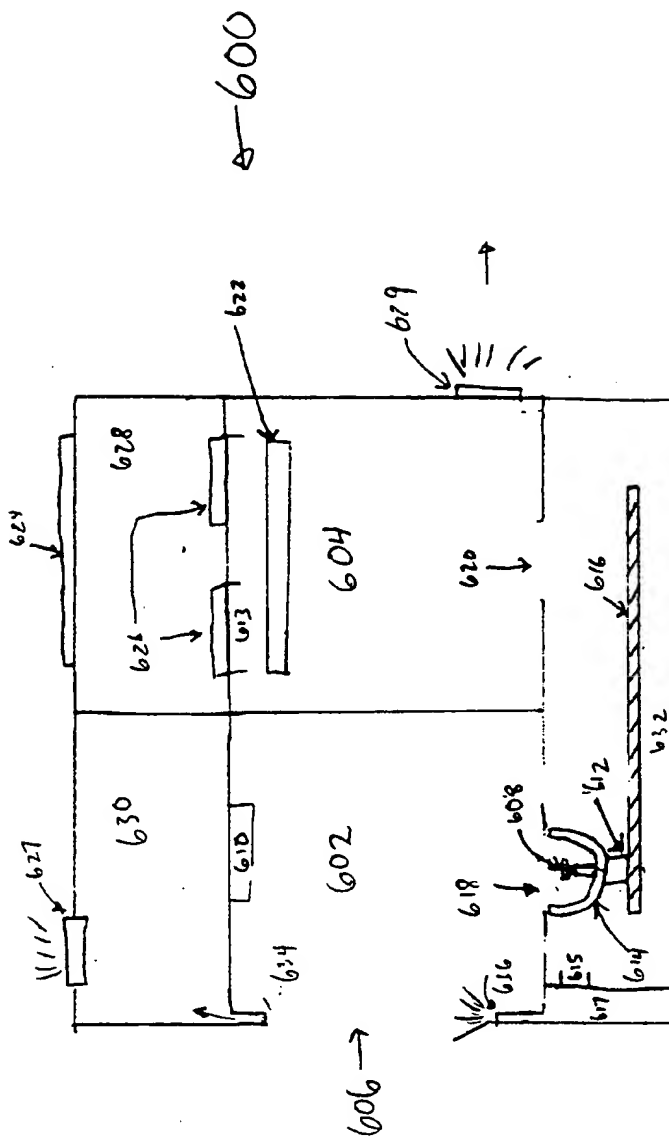
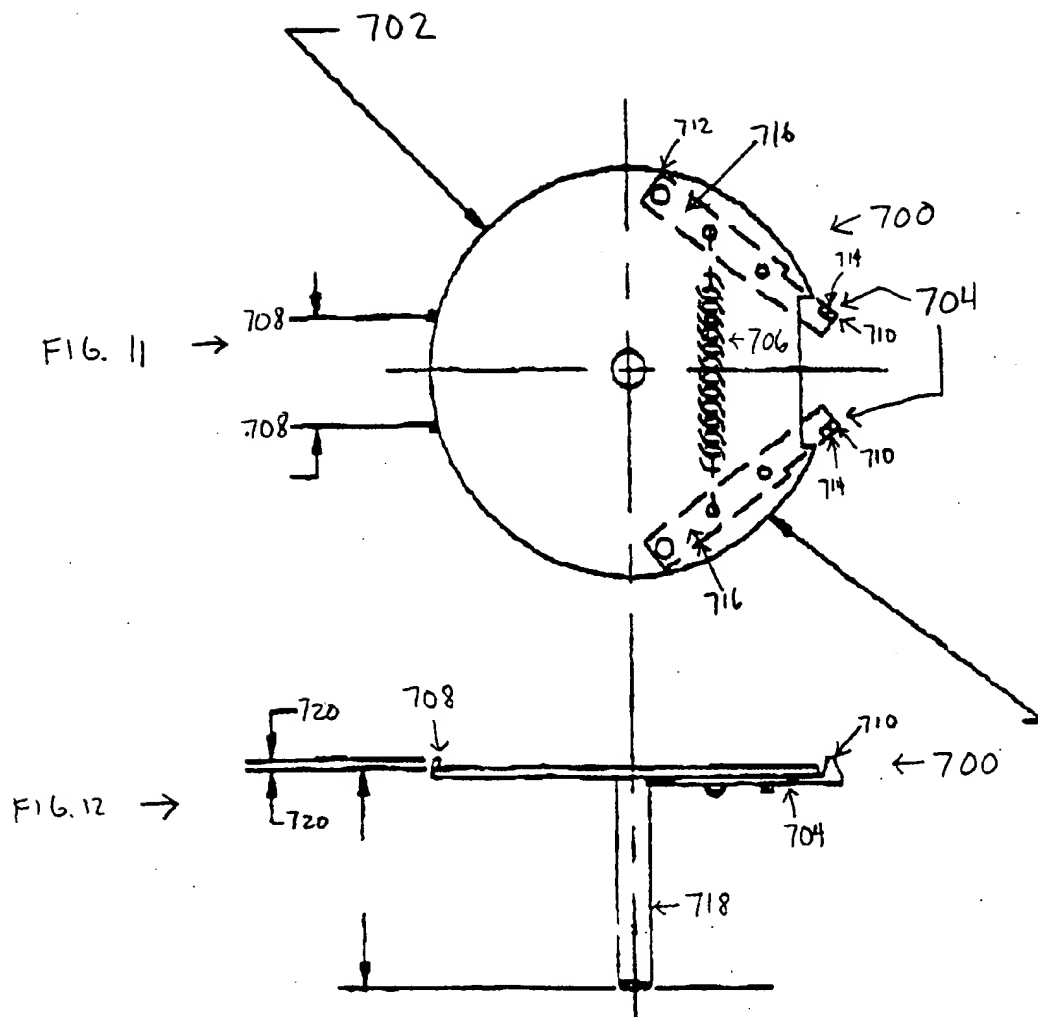


FIG. 10

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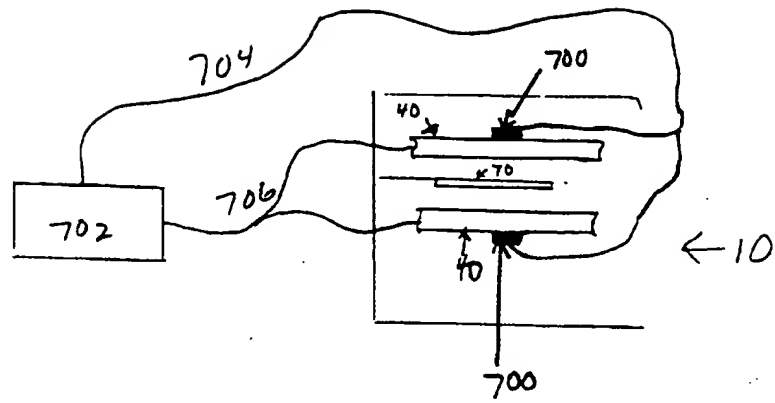
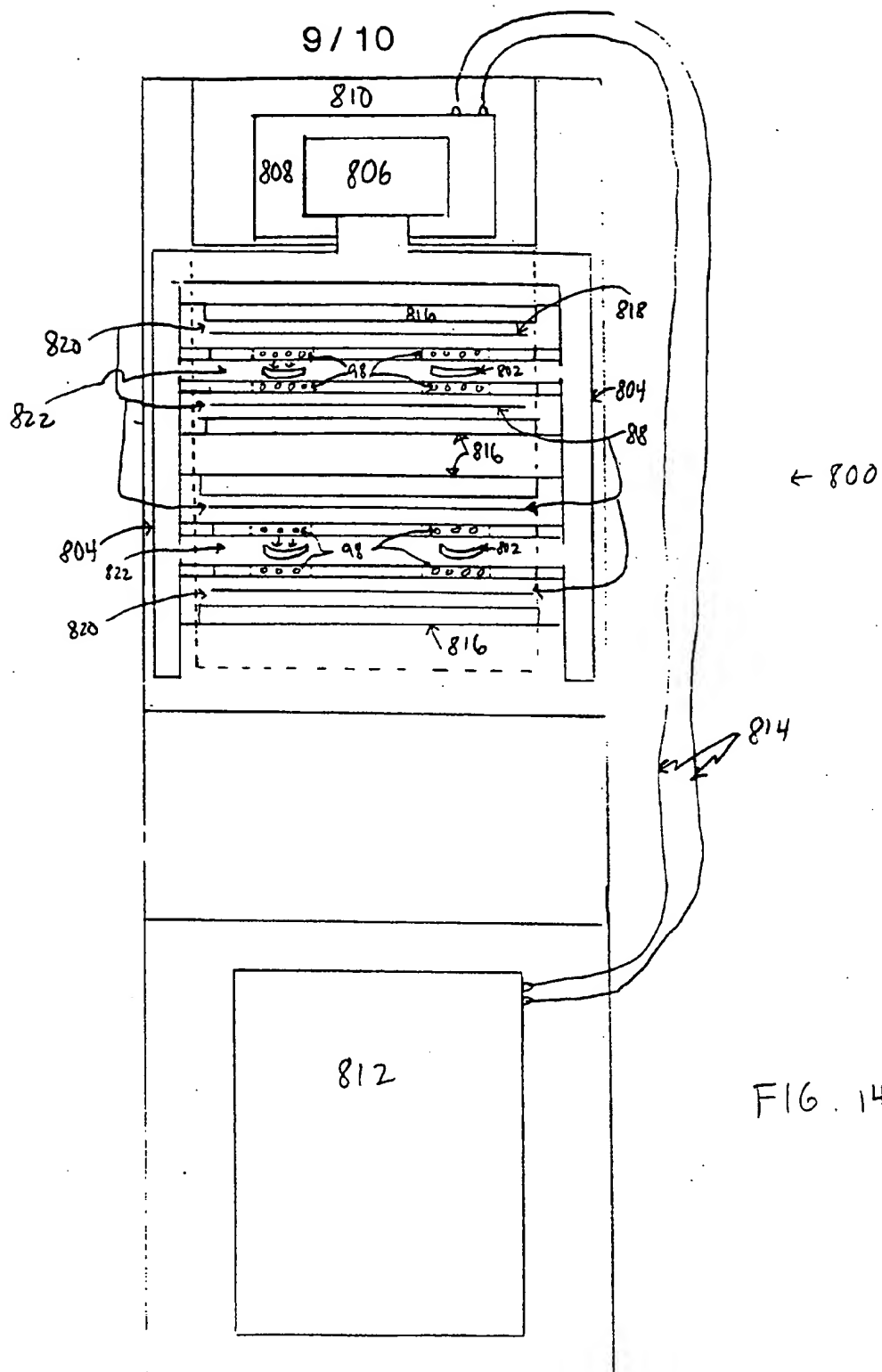
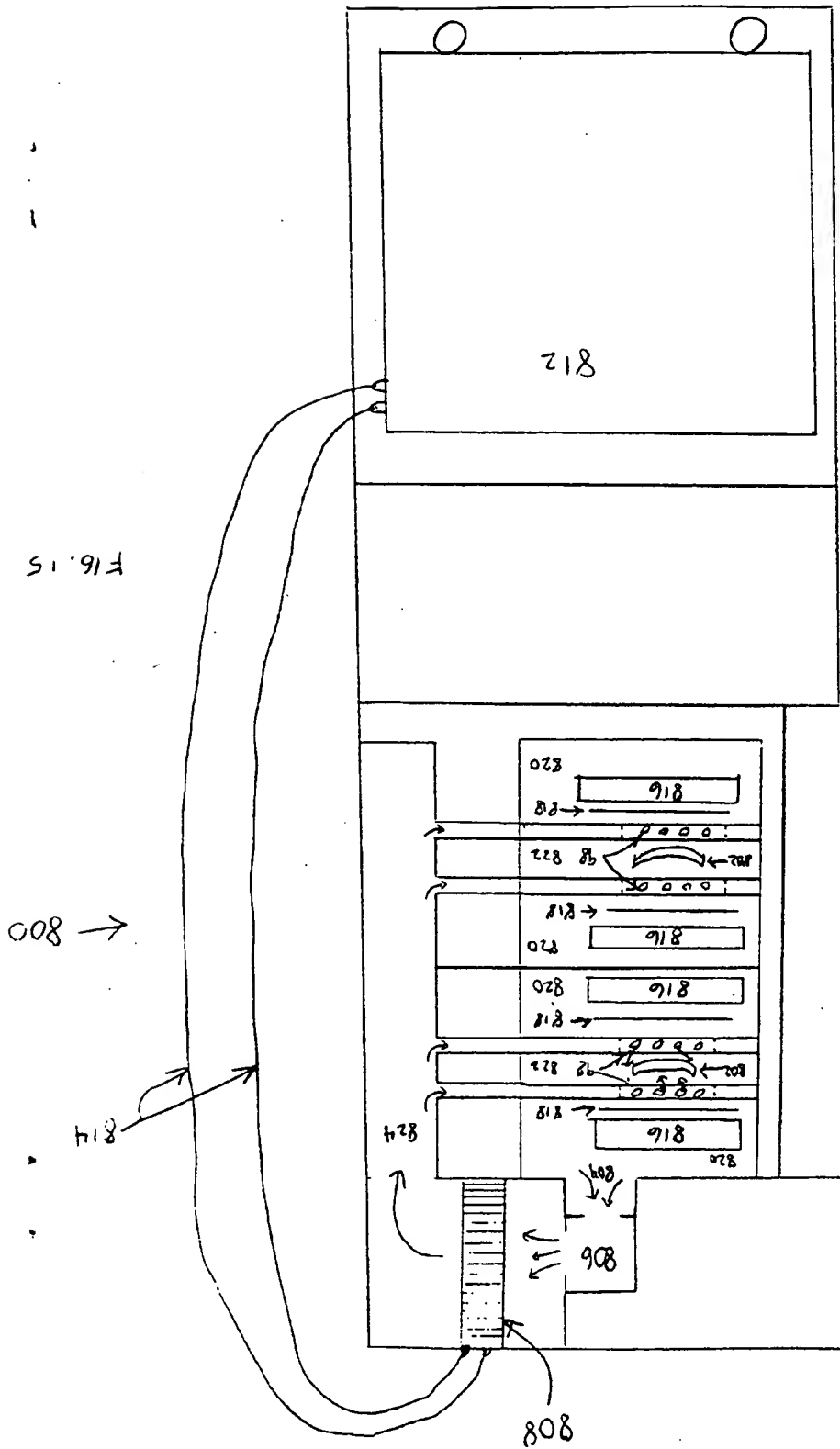


FIG. 13







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